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MANUFACTURING METHODS AND DESIGN PROCEDURES
OF
BRAZED REFRACTORY METAL HONEYCOMB
SANDWICH PANELS (U)

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20 November 1961-20 February 1962

FABRICATION BRANCH
MANUFACTURING TECHNOLOGY LABORATORY
AND
STRUCTURES BRANCH
FLIGHT DYNAMICS LABORATORY
Aeronautical Systems Division
Air Force Systems Command
United States Air Force
Wright-Patterson Air Force Base, Ohio
ASD Project No. 7-937

(Prepared under Contract AF 33(657)-7276 by
Martin Marietta Corporation, Baltimore, Maryland;
J. W. McCown, C. R. Wilks, L. J. Gagola)

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FOREWORD

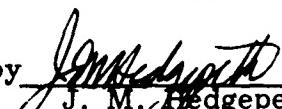
This Interim Technical Documentary Report covers the work performed under Contract AF33(657)-7276 from 20 November 1961 to 20 February 1962. It is published for technical information only and does not necessarily represent the recommendations, conclusions or approval of the Air Force.

This contract with the Space Systems Division of the Martin Marietta Corporation, Baltimore, Maryland, was initiated under ASD Manufacturing Technology Laboratory Project 7-937, "Development of Manufacturing Methods for Brazed Refractory Metal Honeycomb Panels." It is administered under the direction of B. E. Price, Manufacturing Technology Laboratory, Fabrication Branch (ASRCTF) and P. P. Plank, Flight Dynamics Laboratory, Structural Research Branch, ASRMDS-21.

Mr. James W. McCown of Martin Marietta's Structures and Materials Department is the Principal Investigator for the program. Others who cooperated in the research and in the preparation of the report are: C. Wilks and L. Gagola, Structures and Materials Department; and M. M. Schwartz, Manufacturing Research and Development Department.

PUBLICATION REVIEW

Approved by



J. M. Hedgepeth
Manager of Structures and Materials Department

Approved by



K. Jarmolow
Manager of Research and Development Department

ABSTRACT SUMMARY
Interim Technical Documentary Report

ASD-TDR-62-937

**MANUFACTURING METHODS AND DESIGN PROCEDURES FOR
BRAZED REFRACTORY METAL HONEYCOMB PANELS**

James W. McCown
et al.
MARTIN MARIETTA CORPORATION

Honeycomb sandwich panels using molybdenum and columbium core and facings can be brazed to provide lightweight structural coverings for high temperature application on an aerospace vehicle. The panel configurations selected for fabrication simulate a hot structural and a radiant heat shield application. Manufacturing processes and procedures developed in the program will be used to fabricate test panels. Elevated temperature tests will determine thermal and structural capabilities of the test panels.

TZM (Mo-0.5Ti-0.08Zr) molybdenum and D-36 (Cb-10Ti-5Zr) columbium alloys were chosen for use on the program. Available oxidation protection coatings will be selected to protect the panels during high temperature testing.

Special tools and procedures were developed to fabricate the honeycomb core. All molybdenum welding will be accomplished by electron beam welding. A 4200° F cold-wall vacuum furnace will be used to braze the honeycomb test panels.

A quartz-lamp facility will be used to heat the panels for structural testing. Thermal-cyclic and sonic fatigue tests will be performed on heat shield test panels. A 4000° F cold-wall vacuum test chamber will be used to determine material and honeycomb properties.

Symbols

- a, b = Length of panel edge
 c = Subscript denoting "core" or "compression"
 cr = Subscript denoting critical
 D = Sandwich panel bending stiffness
 for thin facings of similar material

$$D = \frac{E' th^2}{2 \lambda}$$

 E = Young's modulus of elasticity
 E_t = Tangent modulus of elasticity
 E' = Effective modulus of elasticity
 F = Allowable stress
 f = Calculated stress; subscript denoting facing
 G = Modulus of rigidity
 h = Distance between facing centroids
 I = Moment of inertia of honeycomb panel per inch of width
 M = Bending moment
 MS = Margin of safety
 N = Load per unit length of edge
 q = Intensity of distributed load
 s = Core cell size, subscript to stress denoting "shear"
 t = Thickness
 u = Subscript to stress denoting "ultimate"
 y = Subscript to stress denoting "yield"
 $\lambda = 1 - \mu^2$
 μ = Poisson's ratio
 p = Density

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I. INTRODUCTION

The purpose of this program is to establish design criteria and to develop manufacturing methods for brazed refractory metal honeycomb-sandwich panels. The panels developed in this program are to be suitable for application on aerospace vehicles as either hot structure or radiant heat shields.

The program is currently in Phase I of a three-phase program: Phase I, Preliminary Studies; Phase II, Panel Manufacturing and Testing; and Phase III, Test Analysis.

Phase I consists of preliminary studies necessary for the manufacturing and testing of honeycomb-sandwich panels and includes: (1) a materials survey of the present state of the art in refractory metals to select one columbium and one molybdenum alloy for use in this program; (2) preliminary structural design and analysis studies to establish test panel configuration and to predict thermal response; (3) a braze alloy study and evaluation to determine the best available braze alloys for use in manufacturing the test panels; (4) a survey of the available oxidation-protection coatings in order to select coating systems for use on the test panels; (5) manufacturing process studies to develop procedures necessary to make the test panel details and to braze the panels; and (6) studies of electron beam welding procedures for manufacturing molybdenum honeycomb core.

All honeycomb core will be manufactured in Phase I of the program.

Phase II consists of the fabrication and experimental evaluation of the honeycomb-sandwich panels. The first step will be to formulate the manufacturing plans and to write the required process specifications and procedures. All manufacturing tooling, detail fabrication and panel brazing will be completed in this phase. After the panels are brazed, oxidation protection coatings will be applied. The completed panels will then be tested in air at temperatures representative of re-entry heating to determine panel structural strength and thermal resistance. Portions of these panels will be cut into small specimens and tested in vacuum to determine material and honeycomb properties.

Phase III of the program consists of analyzing the test results and manufacturing processes to determine the structural strength, thermal capabilities and manufacturing reliability. Design methods and procedures will be established for brazed refractory metal honeycomb-sandwich panels. These methods will incorporate material properties and analytical methods into design charts and curves for panel design.

II. PROGRAM REVIEW AND DISCUSSION

A. MATERIALS SURVEY AND SELECTION

Prior to selecting one columbium and one molybdenum alloy for this program, the properties, fabricability and availability of columbium and molybdenum alloys were reviewed in the literature [1 - 16] * and in discussions with technical personnel of producers and other laboratories. Selection was based on a technical evaluation of all available information. The selected alloys will be tested upon receipt of materials.

The scope and intent of the program limit the selection to currently available alloys. Neither funding nor time has been allocated for any development effort. Candidate alloys must be producible in the thin sheet and foil gages required for this program. This requirement eliminates from consideration those alloys which are basically bar and forging materials, or those limited to heavy gage sheet at this time.

1. Columbium Alloys

Table 1 summarizes those columbium alloys of potential interest for this program. Alloys which are presently available only as bar and forging materials, and alloys in the laboratory development stage are not included. Unalloyed columbium and the Cb-1Zr alloy are also omitted because of strength considerations. The D-31 (Cb-10Ti-10Mo) alloy has not been included because of the welding problems associated with this material.

The short-time properties of these alloys may be compared in Fig. 1 (Ultimate Tensile Strength Versus Temperature) and Fig. 2 (Strength/Weight Versus Temperature). True comparisons of the columbium alloys are complicated by the variety of test conditions, strain rates and specimen conditioning prior to testing. In many cases, the volume of available data is considerably less than is desirable for adequate evaluation. Relative rankings, however, can be made and marked differences are readily apparent.

Structurally, the stronger alloys are of primary interest. F-48 is the strongest alloy, followed by Cb-752. The remaining alloys exhibit more moderate strengths and, on a strength-to-weight basis, fall within a relatively narrow band in the temperature range of interest (2100° to 2800° F).

For consideration in this program, thin sheet and foil gages must be presently available. This criterion virtually eliminates from consideration the stronger columbium alloys. Thin sheet and foil gages appear beyond the present state of the art for F-48. There seem to be no insurmountable problems in rolling the required gages in

*Numbers in brackets refer to the list of references appended to this report.

Cb-752, but a funded program and three to five months of effort are indicated [16] to achieve this. This would require an extension of the program because of the long delivery time; unforeseen problems could jeopardize the extended schedule. Although consideration of this alloy for the program itself is considered premature, inclusion of this alloy to whatever extent possible in the brazing program would be advantageous for later application.

Selection of the columbium alloy for the program must necessarily be restricted to the more moderate strength alloys. These include FS-82 (Cb-33Ta-0.75Zr), D-14 (Cb-5Zr), D-36 (Cb-10Ti-5Zr) and B-33 (Cb-4V). Because similar strength-to-weight ratios characterize these alloys in the temperature range of interest, this factor can be largely discounted in the final alloy selection. These alloys can be made in thin sheet and foil gages, but this has been accomplished only on a limited scale, except for the "older" FS-82 alloy. No real problems are anticipated, however, in the production of any of these alloys in the required sheet and foil gages.

FS-82 has the advantage of greater user and producer experience, but the lower densities (0.28 to 0.306 lb/cu in.) of the newer alloys compared to FS-82 (0.37 lb/cu in.) enhance their attractiveness, particularly where minimum gages characterize design. The heat shield panels in this program are in this category; the lower density alloys will reduce the weight of these panels by 17 to 24% when compared to the FS-82 alloy.

From the three lower density alloys, D-36 was selected and approved as the columbium alloy to be used. The improved oxidation coating capability of the alloy associated with its high titanium content was a dominant factor in the final selection.

2. Molybdenum Alloys

Table 2 lists the molybdenum alloys (Mo-0.5Ti and TZM) of interest for this program. As stated for columbium, alloys which are presently available only as bar and forging materials, or those in the laboratory stages of development, are not included.

Strengthening of molybdenum is accomplished primarily by cold working [9]. Recrystallization of the material, with attendant embrittlement and weakening, must be avoided during processing and subsequent service exposure if the enhanced properties from cold working are to be maintained. For structural panels, recrystallization should be avoided to provide optimum performance; for heat-shield panels, this is desirable but not essential. Resistance to recrystallization is the primary consideration in the selection of molybdenum, contingent again on availability in thin sheet and foil gages.

TABLE 1
Columbium Alloys

<u>Source</u>	<u>Alloy Designation</u>	<u>Alloy Composition</u>	<u>Remarks</u>
Haynes Stellite Corporation	Cb-752	Cb-10W-5Zr	Sheet can be obtained. Foil is considered feasible but would require funding and time for development. Alloy is also made by duPont (D-35)
General Electric Company	F-48	Cb-15W-5Mo-1Zr	Sheet can be obtained but thin gages difficult to produce. Foil is beyond present state of the art. Alloy is also made by Allegheny-Ludlum, Crucible and duPont.
Fansteel Metallurgical Corporation	FS-86	Cb-33Ta-0.75Zr	Sheet and foil can be obtained. Alloy is also made by duPont (D-32)
E. I. duPont de Nemours and Company	D-14	Cb-5Zr	Sheet and foil can be obtained.
	D-36	Cb-10Ti-5Zr	Sheet and foil can be obtained.
Westinghouse Electric Corporation	B-33	Cb-4V	Sheet and foil can be obtained.

<u>Source</u>	<u>Alloy Designation</u>	<u>Alloy Composition</u>	<u>Remarks</u>
Climax Molybdenum Company	Mo-0.5Ti	Mo-0.5Ti	Sheet and foil can be obtained.
Universal Cyclops Steel Corporation	TZM	Mo-0.5Ti-0.08Zr	Sheet and foil can be obtained.
Fansteel Metallurgical Corporation			

The short-time tensile strength as a function of temperature is shown in Fig. 3 for the Mo-0.5Ti and TZM (Mo-0.5Ti-0.08Zr) alloys. The directly comparable data were obtained on bar rather than sheet, but they serve to illustrate the higher strength and improved resistance to recrystallization of the TZM alloy compared to Mo-0.5Ti. Resistance to recrystallization is, of course, time-dependent. It is also sensitive to purity, amount and temperature of working and concurrent straining during annealing. One available comparison [1, 3], utilizing comparable processing, showed that recrystallization of the TZM alloy occurred at a temperature 150° F above that for Mo-0.5Ti.

Figure 3 also includes two additional curves for TZM sheet. The test data [6] pertain to sheet that received about 90% warm-cold work during final processing, which is not representative of optimum conditions for this alloy. The proposed minimum sheet properties are taken from a tentative specification [15] for TZM where high strength is an important requirement.

TZM is the more desirable alloy for service above 2000° F if it can be obtained in the required sheet and foil gages. Until recently, only Mo-0.5Ti has been available, but TZM now has been rolled to foil gages. The TZM alloy, therefore, has been selected and approved as the molybdenum alloy for this program.

B. PRELIMINARY DESIGN AND ANALYSIS STUDY

The purpose of the preliminary design and analysis study is to establish test panel configurations. Such panel configurations, in addition to being suitable for testing also should be representative of an aerospace vehicle application. The test panels will be designed to simulate two different types of vehicle applications; one for a hot structure and the other for a radiant heat shield.

The hot structural application requires that the refractory metal honeycomb withstand structural loading throughout the temperature spectrum of the vehicle. Such an application is limited by the strength and ductility of the refractory material. On the other hand, the heat shield requires only a limited amount of load-carrying ability, but must be able to withstand the extremely high temperatures. At present, operating temperatures of heat shields are limited by the available oxidation coatings.

In this section, design information is presented in the form of design curves and charts.

1. Material Properties

The scarcity and questionable reliability of basic materials data have been mentioned previously. To be able to carry out the design study at this time, however, basic performance data had to be selected on the basis of available in-

formation. When better data are obtained, the analysis will be revised accordingly.

The material tensile strengths [11, 17] selected for the test panel design are those plotted in Figs. 1 and 3 for D-36 and TZM bar. Shear ultimate strengths were estimated to be 50% of the tensile ultimate strength, and compressive ultimate strengths were assumed equal to the tensile ultimate strengths.

The stability design of the test panel requires the use of an effective modulus of elasticity. This term is used for stability design in the elasto-plastic region. The effective modulus used in this study is

$$E' = \frac{2E E_t}{E + E_t}$$

where

E = Young's modulus of elasticity

E_t = Tangent modulus of elasticity.

To determine the effective modulus at the temperatures required in test panel design, it was necessary to select stress-strain curves at various temperatures. Stress-strain curves were reported up to 2400° F for TZM [17]. Young's modulus values were obtained on D-36, but stress-strain data are not available. Predicted stress-strain curves for D-36 were based on Young's modulus and the strengths at 0.001 and 0.002 strain and the ultimate strengths reported [11]. The shape was chosen to be similar to that reported for FS-82 by Fansteel Metallurgical Corporation.

Plots showing the variation with temperature of Young's modulus of elasticity and the modulus of rigidity are given in Fig. 4 for TZM molybdenum and in Fig. 5 for D-36 columbium.

2. Honeycomb Core Properties

The mechanical properties of columbium and molybdenum honeycomb cores were predicted by means of simple theoretical formulae. The cores used for the test panels will be square-cell welded honeycomb. Reduction factors were applied to core material properties to provide a reasonable margin of safety in core strength.

Honeycomb core densities were calculated from the formula

$$\rho_c = \frac{2 t_c}{s} \rho \quad (1)$$

where

t_c = honeycomb foil thickness

s = honeycomb cell size (distance between parallel faces)

ρ = material density.

A nomograph was constructed for determining the honeycomb core density (Fig. 8). Separate curves are shown for the columbium and molybdenum alloys selected. A comparative curve is shown for steel.

The shear strength of the honeycomb core was calculated from the formula

$$F_s = \frac{\rho_c}{\rho} F_{su} \quad (2)$$

where F_{su} is the shear strength of the material used for the honeycomb core. The shear strength of the material was assumed to be 50% of the tensile yield strength at 0.1% offset for the TZM and 50% of the ultimate tensile strength for D-36. The yield, rather than ultimate, strength of the TZM was used as a basis in order to account for loss of properties because of partial recrystallization of the highly worked foils. Although the shear strength should actually be closer to 60% of the tensile strength, a 50% factor was used to provide for other contingencies. For example, Eq (2) assumes that the honeycomb cell walls remain rigid to failure and do not buckle in a tension field web effect. In most honeycomb cores, the tension field web effect occurs prior to failure. Thus, the equation will generally indicate higher strength values than can be obtained in tests. Also, the amount of braze node flow can lower the core shear strength seriously. The estimated core shear strengths are shown in Fig. 9.

The flatwise compressive strength of the honeycomb core was calculated from the formula

$$F_g = \frac{\rho_c}{\rho} F_{cy} \quad (3)$$

where F_{cy} is the compressive yield strength of the material used for the honeycomb core. In the same spirit as the foregoing, the compressive yield strength of the material was assumed to be equal to tensile yield strength at 0.1% offset for the TZM and equal to the tensile ultimate strength for the D-36. Equation (3) will yield only approximate values for the flatwise compressive strength of the honeycomb core. The equation assumes that the honeycomb cell walls remain rigid to failure although the core walls actually buckle at a fairly low stress and the material in the core nodes takes most of the load. The amount of braze node flow, therefore, usually balances out the loss due to buckling. The estimated compressive honeycomb strengths are shown in Fig. 10.

The honeycomb core shear modulus was calculated from the formula

$$G_c = 0.6 \frac{t_c}{s} G \quad (4)$$

where G is the modulus of rigidity of the honeycomb core material. The modulus of rigidity was derived from the relationship:

$$G = \frac{E}{2(1+\mu)} \quad (5)$$

where Poisson's ratio μ was assumed to be 0.3. Equation (4) gives only an approximate core shear modulus. The amount of braze node flow can make as much as 50% difference in the core shear modulus. This not only makes core shear modulus hard to predict, but makes it almost impossible to get consistent test data for evaluation. The core shear modulus is one of the most important parameters in honeycomb design. In order to allow for any unpredictable errors, a reduction factor of 0.6 is used in Eq (4) to give honeycomb design values. The estimated honeycomb core shear moduli are shown in Fig. 11.

The flatwise compressive modulus of the honeycomb core was calculated from the formula

$$E_c = 0.4 \frac{\rho_c}{\rho} E \quad (6)$$

where E is the modulus of elasticity of the honeycomb core material. This formula generally gives high moduli because of the early buckling of the honeycomb cell walls. Again, for design purposes, a reduction factor of 0.4 is used. The estimated flatwise compressive modulus of the honeycomb core is shown in Fig. 12.

The welded square-cell honeycomb core used for the test panels is assumed to be isotropic, a very reasonable assumption with honeycomb core of this type. The node flow of the braze alloy decreases the variation of the core properties with ribbon direction. In general, this variation is less than is experienced in normal test scatter of honeycomb sandwich tests.

An interaction curve for shear and compression in the honeycomb core is given in Fig. 13. This curve is used to determine allowable stresses when the honeycomb core is subjected to combined loads.

3. General Instability Design

The general design formula for panels with isotropic face of similar material of equal thickness is

$$F_{cr} = \frac{\pi^2 K}{4} \left(\frac{h}{b}\right)^2 \frac{E'}{\lambda} \quad (6)$$

where

F_{cr} is the critical stress

$K = K_f + K_m$

K_f is a theoretical coefficient dependent on facing stiffness and panel aspect ratio; K_m

is a theoretical coefficient dependent on sandwich bending and shear rigidities and panel aspect ratio.

$$\lambda = 1 - \mu^2$$

E' is the effective compressive modulus of elasticity.

A direct solution of Eq (6) is impossible because of the dependency of E' on F_{cr} . To allow for a direct solution the equation will be modified to:

$$\frac{F_{cr}}{E'} = \frac{\pi^2 K}{4\lambda} \left(\frac{h}{b} \right)^2 \quad (7)$$

The left side of Eq (7) is a function of the material property and is plotted in Figs. 6 and 7 for TZM and D-36; the right side is essentially a function of the panel geometry.

The general instability equation (Eq (7)) is applicable either to shear instability or compression instability. This is accomplished by using the proper coefficient "K" for either shear or compression. For determination of K, the test panels were assumed to have simply supported ends and edges and an aspect ratio of 1.0. For the test panels, K_f is sufficiently small that it is assumed to be equal to zero. The coefficient K_m is a function of the panel aspect ratio and the parameter

$$V = \frac{\pi^2 t_c t_f E'}{2 \lambda b^2 G_c}$$

as given in Part III of MIL-HDBK-23.

The following iterative procedure was used to determine the required value of effective panel depth h to stabilize the panel. Curves required for the determination of K from V are given in Part III MIL-HDBK-23. The term V is initially assumed to be zero and K is determined. Then Eq (7) is used to determine the value of h. Convergence is obtained in a few cycles of iteration.

Design plots were made for both shear and compression instability. These plots show critical stress versus core thickness with several curves for various temperatures. The compressive plots are shown in Figs. 14 and 15 and the shear plots in Figs. 16 and 17. The plots indicate that there is an effective core thickness after which any increase is structurally inefficient. In order to demonstrate this, a new plot was made showing strength-to-weight ratio versus core thickness (Figs. 18 and 19). Various curves are shown on this plot for separate facing thicknesses.

The honeycomb panel failing in compression or shear instability will sometimes have a final failure in the form of a shear crimp (Fig. 20). This is a result of the panel buckling in short

wavelength, submitting the weak core to high shear stress. The core will fail in shear, relieving the stress in the facings. This will usually allow the remainder of the panel to return to its original shape, leaving the shear crimp as the only apparent failure. To ensure against this type of failure, the panel should be designed to be stable at ultimate load.

4. Local Instability

A local instability failure occurs when the braze or the core fails, causing the facings to buckle at some limited or local area in the panel. There are two basic types of failures that can occur:

Intercellular dimpling. An intercellular dimpling failure occurs when the facing sheet buckles within the cell diameter (Fig. 20). This type of failure is associated with thin skins and/or large core cell sizes. The critical facing stress (from Eq (8)):

$$\frac{F_{c_{cr}}}{E'} = 0.764 \left(\frac{t_f}{s} \right)^{1.5} \quad (8)$$

where

t_f = facing thickness

s = core cell size

is given in Figs. 21 and 22 for TZM and D-36, showing the effects of facing thickness, cell size and temperature. Equation (8) is empirical. It was written to fit all available test data as well as possible, and appears to give reasonable critical dimpling stress.

Face wrinkling. A face wrinkling failure occurs when the braze or core strength is insufficient to stabilize the facing. This type of failure usually occurs in a small local area, with the facing buckling into the core if the core strength is insufficient, or with the facing buckling away from the core if the braze strength is insufficient (Fig. 20). This type of failure is associated with low braze strength or core strength. There are no acceptable design procedures for face wrinkling. Current recommendation in MIL-HDBK 23 calls for tests to establish face wrinkling strength.

The face wrinkling strength is dependent on the braze strength and core compressive strength, and is directly dependent on the size of the braze fillet. Braze fillet affects the face wrinkling strength in two ways; first, by giving more braze contact area to resist tension and secondly, by adding better support to the honeycomb core so that it may be stressed to a higher load prior to buckling. It is exceedingly difficult to obtain uniform fillet size from panel to panel, making it almost impossible to obtain controllable test results with which an acceptable empirical equation could be written. Exactly what mechanism

causes the first failure is also unknown. A usual case is where a thin-faced sandwich panel starts to have elastic or plastic dimpling of the facings. This causes increased stress in the core and braze alloy, which leads to a face wrinkling failure; the failed panel appears to have a face wrinkling failure, while the original failure mechanism was that of intercellular dimpling.

Since there are no acceptable procedures to design for face wrinkling, the best practice is to make the ratio of the core density to facing thickness similar or larger than that found on brazed panels where there are sufficient data. If the core and braze strength are sufficiently high, then the facing can be stressed to ultimate strength before failure occurs. The problem is to determine what is "sufficiently high core strength." The strength can be increased by using a denser or stronger core, but for a given temperature and braze alloy, the only way to increase braze fillet strength is to decrease the core cell size, thus increasing the braze contact area to give more braze strength.

A 3/16-inch square cell honeycomb core made from 0.002-inch thick foil was chosen for the test panel design. This design should provide sufficient core strength to prevent a local instability failure from crushing the core.

5. Strength-to-Weight Study

A study was made to demonstrate the effect of panel core thickness on the ratio of strength-to-weight for general instability failure. The weight of the braze alloy was not included in this study, as it does not ordinarily vary with core thickness, and can therefore be considered as a constant additive weight.

The results of these calculations for a temperature of 2200° F are given in Figs. 18 and 19, which show variation of the strength-weight ratio with core thickness for several facing thicknesses. In every case, there exists a core thickness which produces the highest strength-to-weight ratio. The calculations also were made for other temperatures, and the resulting optimum core thicknesses were found. Overall results are given in Figs. 23 and 24 and show the optimum core thickness and resulting compressive strength of the test panel at various temperatures and facing thicknesses.

6. Thermal Stress Discussion

An investigation has been made of the ability of a sandwich panel to withstand thermal stress caused by a thermal gradient through the panel. A configuration of a continuous sandwich panel over simple supports was assumed such as would be found on a vehicle surface of panels with moment continuity across supports at spars or bulkheads.

The following conditions were assumed:

- (1) The covering was heated uniformly over the surface. Consequently, the only thermal gradient was through, not along the sandwich panels. The thermal stresses, therefore, resulted only from the difference in uniform temperature between the inner and outer sandwich facings.
- (2) Thermal bending of the sandwich panel was prevented by the clamped-edge effect of the moment continuity between adjacent panels [18].
- (3) The supporting substructure did not prevent the heated panel from expanding in its plane. The compressive forces in the hotter outer facing were equilibrated by equal and opposite forces in the colder inner facing. Since the inner and outer facings both have the same thickness, their stresses were equal and opposite.
- (4) Poisson's ratio " μ " was independent of strain and temperature and equal to 0.3 for both facings.
- (5) The facings had isotropic material properties.
- (6) There were no loads applied to the panel, hence the stresses were only those resulting from the temperature distribution.

The plane-stress Eqs [18-a] were written as

$$\epsilon_x^{\text{total}} = \alpha \Delta T + \frac{1}{E_s} (\sigma_x - \mu \sigma_y),$$

where

α = linear coefficient of thermal expansion in./in. °F

ΔT = difference between facing temperature and 70° F

E_s = secant modulus of the stress-strain curve of a facing at its specified temperature, psi.

Due to isotropy of the facings, their constraints and their temperatures,

$$\sigma_x = \sigma_y$$

The total strains for the inner and outer facings became

$$\epsilon_i = \alpha_i \Delta T_i + (1 - \mu) \frac{\sigma_i}{E_{s_i}} \quad (9a)$$

and

$$\epsilon_o = \alpha_o \Delta T_o + (1 - \mu) \frac{\sigma_o}{E_{s_o}} \quad (9b)$$

respectively.

The total strain of the inner facing equaled that of the outer facing according to assumption (2) above, so that expressions (9a) and (9b) could be equated. The stress of the inner facing was equal and opposite to that of the outer facing, by assumption (3). Equations (9a) and (9b) were accordingly combined to give the thermal stress equation:

$$\sigma_o = -\left(\frac{E_{s_o}}{E_{s_o} + E_{s_i}}\right) \left[\frac{\alpha_o \Delta T_o - \alpha_i \Delta T_i}{(1 - \mu)} \right] \quad (10)$$

Since E_{s_o} and E_{s_i} were functions of the strains, σ_o was not directly solvable from Eq (10).

Equation (10) has been solved by trial-and-error application of the stress-strain curves of the inner and outer facings at their various temperatures. The results have been plotted as curves of stress versus outer facing temperature for various inner facing temperatures in Figs. 25 and 26 for TZM and D-36, respectively.

It may be seen from Figs. 25 and 26 that the thermal stresses did not become high enough to rupture the inner facing. However, the stresses in the outer facing caused inelastic strains at the higher temperatures, which may be sufficient to cause inelastic intercellular dimpling. The stresses required to produce such dimpling have been plotted in Figs. 21 and 22 for various facing thicknesses, cell sizes and facing temperatures.

The panel thickness did not enter the thermal stress equation. However, the thermal strain differential ($\alpha_o \Delta T_o - \alpha_i \Delta T_i$) is greater for thicker panels, so it is expected that greater thermal stresses would occur in thicker panels.

7. Test Panel Design

The structural test panel designs are shown in Drawings No. SK 46841 and SK 46842 of Appendix D of this report. The heat shield designs are shown in Drawings No. SK 46843 and SK 46844. The test panels were designed for simplicity and to simulate actual aerospace vehicle application. Some of the bend radii on the test panel edge members and facings will have to be determined during the manufacturing phase of the program. "U" channel edge members on the structural panels will be formed and welded to form a picture frame prior to brazing. The honeycomb core will be individually matched to these frames.

A 0.5-inch core thickness for the structural test panels was selected because:

- (1) This thickness is sufficient to stabilize the panels for shear and compression testing.
- (2) Strength-to-weight studies indicate this core thickness to be near optimum.
- (3) Examination of all factors (Figs. 14 through 19, 23 and 24) and past experience indicate that any increase of core thickness over approximately 0.5 inch would have little, if any, effect on the test panel strength.

All panels will be hermetically sealed by welding to protect the braze alloy from the oxidation-protection coating and the core from high temperature air during testing.

The edges on the structural panel are adaptable to either a bolted or welded joint. Edges on the heat shield panels are made so that the panels can be used in modular construction of a space vehicle covering. The specially designed edges will provide for a minimum gap. This type of design is especially adaptable because the panel corners do not have to meet at all locations in order to provide a simple covering.

For simplicity, and in order to provide an excellent comparison between TZM molybdenum and D-36 columbium, the test panels were designed identical for both alloys. The curved panels are designed to have a 30.985-inch radius of curvature. This radius should provide a very reasonable indication of the ability to make curved panels but is not too small to make panel and small specimen testing too difficult or of questionable value.

The heat shield panels were designed with support clips and an access hole similar to those used by Bell in their double-walled structures program [21]. These clips will be preassembled and brazed with the panel. The electron beam welder will be used to seal all exposed braze joints.

8. Test Panel Analysis

Structural panels. The structural panels (see Drawings No. SK46841 and SK46842) were designed to simulate full-scale space vehicle structural panels. Panel performance will be evaluated by elevated temperature tests. However, actual test temperatures of the panels cannot be determined until a braze alloy is selected and evaluated. The results of the design study indicate that the maximum efficient structural temperature of the D-36 is about 2100° F. The maximum efficient structural temperature of the TZM is about 2400° F, if a braze alloy can be found with a higher remelt than braze temperature. If not, the test temperature may have to be lowered accordingly.

The compression-test panels should be stable to ultimate compressive strength of the material. Because of the testing at high temperature, the

panels will probably fail in face wrinkling, with the face buckling away from the core and the braze failing in tension. The shear-test panels should fail in the same manner as the compression panels.

The absence of sufficient material property data makes it impossible to predict accurately the ultimate strengths of the test panels. Since there are no aerospace vehicle loads available with which to compare the strengths, margins of safety will not be determined for the structural panels.

By assuming a test temperature of 2100° F for D-36 and 2200° F for the TZM, the following critical stresses were obtained from the referenced illustrations.

(1) General instability

Compression

$$\text{TZM } F_{c_{cr}} = 56,500 \text{ psi} \quad (\text{Fig. 14})$$

$$\text{D-36 } F_{c_{cr}} = 18,000 \text{ psi} \quad (\text{Fig. 15})$$

Shear

$$\text{TZM } F_{s_{cr}} = 58,000 \text{ psi} \quad (\text{Fig. 16})$$

$$\text{D-36 } F_{s_{cr}} = 18,500 \text{ psi} \quad (\text{Fig. 17})$$

(2) Intercellular dimpling

$$\text{TZM } F_{c_{cr}} = 54,500 \text{ psi} \quad (\text{Fig. 21})$$

$$\text{D-36 } F_{c_{cr}} = 17,500 \text{ psi} \quad (\text{Fig. 22})$$

The critical dimpling stresses as calculated are lower than the general stability stress. The lowest critical stress is felt to be local stability or face wrinkling with a braze failure allowing the facing to buckle away from the core.

The load-carrying capacity of brazed refractory honeycomb panels used as a hot structure on an aerospace vehicle is directly affected by any thermal stress in the panels. To complement a method presented previously for calculation of thermal stress, an analysis by Swann and Pittman [19 and 20] was programmed for the IBM 1620. With this procedure, a thermal gradient through a honeycomb panel can be determined for any applied time-temperature input. Two thermal cycles were analyzed for both the columbium and the molybdenum honeycomb panels. The primary variable in the analysis procedure is honeycomb panel thickness. With this analysis and the thermal stress analysis, an adequate evaluation of the effect of panel thickness on thermal stress can be ascertained. The analysis is presented in Appendix B.

Heat shield panels. The heat shield panels (see Drawings Nos. SK 46843 and SK 46844) were designed as modular elements for outer surface heat shields on a space vehicle [21]. Present knowledge concerning material, brazing and oxidation protection coating indicates that the heat shield panels should be capable of service environment at or near 3000° F.

The primary structural load in the heat shield panel is caused by the dynamic pressure on the outer surface. This air pressure causes bending stress in the panel and shear and compression stress in the honeycomb core. A method for the stress analysis of the heat shield panels is presented in Appendix C. Assuming an effective air load of 1.2 psi at 3000° F, the following critical stresses were determined:

(1) Facing stress

$$\text{TZM } f_c = 3000 \text{ psi} \quad (\text{Fig. 31})$$

$$\text{D-36 } f_c = 3000 \text{ psi} \quad (\text{Fig. 31})$$

(2) Core stress

Compression

$$\text{TZM } f_g = 50 \text{ psi} \quad (\text{Fig. 32})$$

$$\text{D-36 } f_g = 50 \text{ psi} \quad (\text{Fig. 32})$$

Shear

$$\text{TZM } f_s = 35 \text{ psi} \quad (\text{Fig. 33})$$

$$\text{D-36 } f_s = 35 \text{ psi} \quad (\text{Fig. 33})$$

The allowable stresses as can best be determined for the conditions are:

(1) Facing stress

Intercellular dimpling

$$\text{TZM } F_{c_{cr}} = 6500 \text{ psi} \quad (\text{Fig. 21})$$

$$\text{D-36 } F_{c_{cr}} = 3200 \text{ psi} \quad (\text{Fig. 22})$$

(2) Core stress

Compression

$$\text{TZM } F_g = 390 \text{ psi} \quad (\text{Fig. 10})$$

$$\text{D-36 } F_g = 100 \text{ psi} \quad (\text{Fig. 10})$$

Shear

$$\text{TZM } F_s = 180 \text{ psi} \quad (\text{Fig. 9})$$

$$\text{D-36 } F_s = 50 \text{ psi} \quad (\text{Fig. 9})$$

The following margins of safety were determined for the heat shield test panels:

(1) Facings

$$\text{TZM } MS = \frac{F_c}{f} - 1 =$$

$$\frac{6500}{3600} - 1 = +1.16$$

$$\text{D-36 } MS = \frac{F_c}{f} - 1 =$$

$$\frac{3200}{3000} - 1 = +0.06$$

(2) Core

$$\text{TZM } R_g = \frac{f_g}{F_g} = \frac{50}{390} = 0.128$$

$$R_s = \frac{f_s}{F_s} = \frac{35}{180} = 0.196$$

$$MS = \frac{0.83}{0.196} - 1 = +2.85 \quad (\text{Fig. 13})$$

$$\text{D-36 } R = \frac{f_g}{F_g} = \frac{50}{100} = 0.5$$

$$R = \frac{f_s}{F_s} = \frac{35}{50} = 0.7$$

$$MS = \frac{0.725}{0.7} - 1 = +0.02 \quad (\text{Fig. 13})$$

The D-36 columbium heat shield panels are the most critical structural items. It was originally believed that the heat shield panels should be 0.25 inch thick instead of the 0.375 used, but the 0.25-inch thick panel resulted in negative margins.

C. OXIDATION PROTECTION COATING SURVEY

Protective coatings for TZM molybdenum and D-36 columbium will be required for the panel test exposure conditions in this program.

Coatings for molybdenum and columbium were reviewed in the literature [6, 22 to 36] and in discussions with technical personnel of coating producers and other laboratories. While the survey is complete, the information obtained is still being evaluated.

Concurrent with this program, aluminum-tin coatings for the protection of molybdenum and molybdenum alloys have been separately investigated.

1. Molybdenum

No attempt was made to review in detail all of the coating systems which have been studied for the protection of molybdenum and molybdenum alloys. Preliminary examination revealed that many were not pertinent to the program requirements. Others are still primarily in the laboratory stage and not yet advanced to hardware application. Facilities must be adequate to coat 12 by 12 inch panels (16 by 16 inches including attendant test fixturing).

Coatings for molybdenum, applicable in the temperature range of interest, primarily are silicides or complex silicides obtained by alloying with metallic additions. Such coatings have been developed by Pfaudler [25, 29], Vought [27], Chromalloy [27, 34] and Chromizing Corporation [27]. Table 3 gives a summary of the potentially applicable coatings for molybdenum. The silicide types are generally proprietary coatings and pack cementation is employed for application. Comparative data for similar test conditions are limited. The silicide-type coatings are vulnerable to edge failure; special precautions must be taken to round edges and to eliminate sharp corners. Reported performance of these coatings is generally adequate in the thermal environment contemplated for the tests to be conducted in this program. Coating reliability is more difficult to assess, particularly with reference to the correlation of test data on coupon-type specimens with performance on full-scale parts.

The Al-Sn coating system, developed by Sylcor [30, 31] on an ASD contract to protect tantalum, appears to have good potential for molybdenum. Reliability and performance at high temperatures appear excellent. Cyclic oxidation tests were conducted in a plasma jet facility on a number of specimens from different batches of coated material. Coating life at 3100° F ranged from 13 to 22 five-minute cycles and averaged 18 five-minute cycles (1.5 hours). Specimens were cooled to room temperature after each heating cycle. Comparable life (17 five-minute cycles at 3100° F) was obtained on a specimen with a 1/16-inch diameter hole drilled through the specimen after coating; self-healing of the uncoated edge of the hole was apparently achieved by flow of the liquid phase of the coating to this area and the formation of the required diffusion layer during oxidation testing. Eventual failure of the specimen did not occur at this hole.

Anomalies in lower temperature performance (furnace exposure at 2000° to 2500° F) have been observed. No immediate failures on heating to temperature have been noted.

Edge preparation appears unnecessary. All coating work has been done on specimens with as-sheared edges, and edge failures have not been a problem. Scaling up appears to be no

TABLE 3
Protective Coatings for Molybdenum-Base Alloys

Source	Coating Name	Application Method	Preparation of Substrate	As Applied Composition	Remarks
Pfaudler	PFR-6	Pack cementation	Critical	Proprietary--coating consists of Si plus one or more metallic additions.	Commercially available. Facilities for coating 16 x 16-inch specimens.
Chromalloy	W-2	Pack cementation	Critical	Proprietary-- reported as being intermetallic but not silicides.	Commercially available. Facilities for coating 16 x 16-inch specimens.
Chromizing Corporation	Durak MG	Pack cementation	Critical	Proprietary-- similar to W-2.	No response to inquiry for Mo coating.
Vought Astronautics	Vought II, IV	Pack cementation	Flexible	Proprietary--coating consists of various intermetallics including borides (when introduced) and silicides.	No response to inquiry.
Sylvania	40S	Dip, brush or spray	Flexible	Aluminum-tin	Commercially available. Facilities for coating 16 x 16-inch specimens.

problem technically, requiring only vacuum heat treat facilities of adequate size for the parts to be coated. Presently, 6 by 6 inch sheets have been coated and subsequently exposed without failure to 6 five-minute cycles at 3000° F in a quartz-lamp facility. A 4-inch diameter disc was successfully exposed in a hot gas facility for 30 minutes at 2300° to 2750° F (Figs. 34 and 35).

2. Columbium

Major research and development on protective coatings for columbium is relatively new compared to that of molybdenum.

Current columbium coating systems of potential interest for this program are, as in the case of molybdenum, largely based on complex silicides for protection. The systems are in general more complex, with multi-layers of complex chemistry quite common. Application techniques vary widely.

Columbium coatings include those developed by Vought [32], Chromalloy [34], Chromizing Corporation [27], Pfaudler [29], General Electric [6], and Thompson Ramo-Wooldridge [22, 33]. Table 4 gives a summary of the potentially applicable coatings for columbium.

Comparative data on the performance of six columbium coatings were reported on an ASD coating evaluation study [22], but several of the coatings reportedly have been improved since this study was completed. The Thompson Ramo-Wooldridge coating performed best under the test conditions employed in this study. The Pfaudler coating was not included in this ASD evaluation program.

Further study and consideration of the several coating systems available for both columbium and molybdenum are presently under way. Coatings will be chosen with consideration of end product utility as well as of the more limited requirement to permit performance of the test program. Every effort will be made to select the best coating system available for each material. A decision will be made during the next quarter on which coatings to recommend for evaluation and approval.

D. BRAZING STUDY AND EVALUATION

1. Braze Alloy Selection

A literature survey [37 to 43] was made prior to selecting braze alloy systems for evaluation with the two base materials, TZM molybdenum and D-36 columbium.

Selection of the braze alloys for evaluation was governed by the desired applications (hot structure or heat shield) and their operational temperatures. For structural application, TZM molybdenum panels should be limited to tem-

peratures below those which will cause recrystallization (about 2600° F for very short periods, 2400° to 2500° F for longer exposures). Structural panels of D-36 are not similarly restricted. Heat shield panels of both alloys should be capable of operational temperatures approaching 3000° F.

Braze temperature restrictions for both alloys include:

(1) TZM molybdenum

Structural panels. Material should not be recrystallized during brazing.

Heat shield panels. Braze strength should be sufficient to withstand low loading at 3000° F. Braze-remelt should be greater than 3100° F.

(2) D-36 columbium

Structural panels. There are no braze temperature restrictions, except for possible grain growth problems. Maximum contemplated operational temperature is about 2600° F.

Heat shield panels. Braze strength should be sufficient to withstand low loading at 3000° F. Braze-remelt should be greater than 3100° F.

Generally, the maximum operational temperature of a brazed structural panel is approximately 200° to 300° F lower than the brazing or melting temperature of the filler alloy. With conventional filler alloys that braze and remelt at the same temperature, structural TZM molybdenum panels would be limited to a maximum service temperature of about 2300° F. Braze alloys, which would braze below the recrystallization temperature and not remelt at 2900° F or higher, would permit the structural panels to be employed at higher temperatures. Because extended exposure of TZM [9] above 2400° F will cause recrystallization eventually, structural applications above this temperature should be limited to short time periods. The ability to withstand a short time environment above 2400° F is extremely desirable in view of certain aerospace vehicle applications.

A development study was initiated to find an acceptable high remelt alloy system. The literature survey [39 to 43] revealed that several methods to develop high remelt temperature braze alloys are being investigated. Reported techniques include:

- (1) Volatilization of a liquidus temperature depressant.
- (2) Exothermic reaction brazing.
- (3) Diffusion alloying and diffusion of a liquidus temperature depressant.

TABLE 4
Protective Coatings for Columbium-Base Alloys

<u>Source</u>	<u>Coating Name</u>	<u>Application Method</u>	<u>Preparation of Substrate</u>	<u>As Applied Composition</u>	<u>Remarks</u>
Pfaudler	Several	Pack cementation	Critical	Proprietary--either silicides alone or codeposited with one or more elements of class Mo, W.	Commercially available. Facilities for coating 16 x 16-inch specimens.
Chromalloy		Pack cementation		Proprietary	Available--experimental. Facilities for coating 16 x 16-inch specimens.
Chromizing Corporation	K-S	Pack cementation		Proprietary	Available--experimental. Facilities for coating 16 x 16-inch specimens.
Thompson Ramo-Wooldridge	Chromium-Titanium-Silicon Base	Two-cycle pack cementation	Critical	Inner layer--Cr+Ti+Cb outer layer--silicon alloyed with Cr+Ti.	Commercially available. Facilities require expansion for coating 16 x 16-inch specimens.
Vought Astronautics	Vought I Cb and II Cb	Pack cementation	Critical	Coating consists of various intermetallics including borides (when introduced) and silicides.	No response to inquiry.
General Electric Company	LB-2	Dip, brush or spray		Cr--aluminum alloy	Presently unavailable because of prior commitments.

Volatilization technique. The volatilization technique [40] is a two-step process. Liquidus temperature depressants such as lithium, phosphorus or indium are added to the basic filler alloy. The initial braze must be made in an inert atmosphere at ambient pressures to retain the volatile constituent until melting has occurred. Upon completion of the reaction, the brazement is subjected to low pressures (vacuum) where volatilization of the liquidus temperature depressant is effected. The remelt temperature of the braze alloy is thus increased; increases in remelt temperature on the order of 800° F can be realized by employing this technique.

Exothermic reaction brazing. Exothermic reaction brazing [42] is a process wherein both the heat for brazing and the braze alloy are produced by the exothermic reduction of compounds of the alloy elements by a more reactive element. This technique is still in the early development stages. Further investigation in the present program does not appear warranted because of time limitations. However, this process may prove very useful for later application.

Diffusion alloying. Diffusion alloying and subsequent diffusion of the liquidus temperature depressant appears to be the most promising method [39] to attain high remelt temperature braze alloys. Several alloy systems (Table 5) have been selected for evaluation with both the molybdenum and columbium base materials. Preparation of these high remelt temperature alloys is in progress. Efforts will be made to develop these alloys and techniques for their utilization in the program within the time period available for braze alloy evaluation and selection. With this method, increases in remelt temperature in excess of 1500° F have been reported. The use of a high remelt temperature braze alloy would be advantageous for fabrication of the molybdenum structural panels in that the maximum application temperature could be increased.

The principle of diffusion alloying to achieve high remelt temperature is the addition of an element to the basic braze alloy to act both as a liquidus temperature depressant and a diffusant. Elements such as boron and silicon are excellent examples. In the case of platinum, an addition of 3.5% boron decreases the melting point of platinum approximately 1500° F. Braze-remelt temperatures as high as 3800° F for this system have been achieved in studies with tungsten [39]. It has been indicated that the possible mechanism involved in obtaining a high remelt temperature for this alloy system depends on alloying of the major filler metal constituent with the base material and the reaction of the liquidus temperature depressant with the base alloy to form high melting temperature intermediate compounds. In some instances, the base material deliberately has been added in powdered form to the filler alloy to ensure completeness of the reaction and/or reduce the fluidity of the braze material. Published data [39] show dubious benefits of additional base material on remelt temperature;

also, long time diffusion treatments after initial brazing appear to have little effect on remelt temperature.

Every effort will be made to utilize this brazing principle where possible in the present program.

2. Braze Alloy Evaluation

To determine the characteristics of the selected brazing alloys, T-joint, laminate and sandwich panel specimens (Fig. 36) are being used for evaluation. The T-joint specimen serves as an initial visual screening test for braze alloy wettability and filleting characteristics. Subsequent metallographic examination of the joint is made to determine:

- (1) Type of bond (mechanical or metallurgical).
- (2) Alloying and/or diffusion characteristics of the filler alloy.
- (3) Erosion effects.

Laminate specimens are helpful in determining the wetting action of a braze alloy over large faying surface areas and are representative of an edge-member-to-panel skin joint. The honeycomb sandwich specimen is used for the final evaluation of promising braze alloys. Action of the braze alloy on the thin foil core is checked both visually and metallographically. Each of the alloys selected for evaluation is subjected to these screening tests. Final selection of a braze alloy for the TZM molybdenum and D-36 columbium structural and heat shield panels will be contingent on the performance of the alloys in these tests.

During this reporting period, a number of braze alloys have been evaluated for both refractory metal alloys, but the major portion of the evaluation work to date has been conducted on TZM.

The brazing studies are being conducted in a cold-wall vacuum furnace (Fig. 37). This furnace has a 13 by 13 by 12 inch heating zone with tantalum strip heater elements.

All specimens are being chemically cleaned prior to brazing, employing the following solutions:

Molybdenum	Columbium
95% H ₂ SO ₄	10 to 15% HF
4.5% HNO ₃	60% HNO ₃
0.5% HF	H ₂ O balance
18.8 g/l Cr ₂ O ₃	

Both of these solutions are heated to 120° to 140° F; immersion times are 3 to 5 minutes.

TABLE 5
Braze Alloy Selection for Study and Evaluation

<u>Braze Alloys</u>	<u>Composition</u>	<u>Braze Temperature (°F)</u>
Haynes 25	55Co, 20Cr, 15W, 10Ni	2600
Inconel	80Ni, 14Cr, 6Fe	2550
TZB	48Ti, 48Zr, 4Be	2600
Palladium-copper	60Pd, 40Cu	2250
Palladium	100Pd	2900
Titanium	Commercially pure	3100
Platinum-boron	96.5Pt, 3.5B	1600 (estimated)
Palladium-silicon	95Pd, 5Si	1500 (estimated)
Palladium-boron	99Pd, 1B	1800 (estimated)
Platinum-silicon	99.5Pt, 4.5Si	1550 (estimated)
Palladium-aluminum	93Pd, 7Al	2000 (estimated)
Palladium-beryllium	97Pd, 3Be	1750 (estimated)
TZB-2	46Ti, 46Zr, 8Be	2200 (estimated)

TZM braze alloy evaluation. Five braze alloy systems (Table 6) have been evaluated with the base alloy TZM: Haynes 25, Inconel, TZB (48 Ti-48 Zr-4 Be), palladium and titanium. The Haynes 25 alloy system exhibits satisfactory brazing characteristics for the structural panels. This alloy flows at 2600° F and exhibits excellent filleting characteristics (Fig. 39). The filler alloy forms a metallurgical or alloy bond with the base material. The alloy zone is relatively narrow and erosion of the parent metal is negligible.

Figure 40 shows a cross section of a laminate specimen brazed with Haynes 25. No void areas were noted in the cross sections examined, indicating excellent wetting action of the braze alloy. In order to protect the braze alloy during application of the oxidation protection coatings, the edge-member-to-skin braze must be hermetically sealed. The proposed method for sealing is electron beam welding. Figure 41 shows that this technique is feasible; no detrimental effects on the weld joint were noted as a result of braze alloy dilution with the parent material.

A section of honeycomb panel was brazed with Haynes 25. A photograph of the panel emphasizing the core-to-skin juncture is shown in Fig. 42. It is worthwhile to note that this panel was subsequently sectioned for metallographic examination of the brazed joints (Fig. 43) without shattering the honeycomb core. Although the core recrystallized, it had sufficient ductility to permit sectioning.

A recrystallization study was conducted on 0.002-inch TZM foil. This material was completely recrystallized after 5-minute exposure at 2600° F, with subsequent grain growth for longer periods (Fig. 38). The 0.015-inch TZM sheet used in the brazing studies did not recrystallize after 5 minutes at 2600° F (Fig. 39). The differences in recrystallization behavior between the foil and sheet material are to be expected, since the recrystallization temperature of molybdenum alloys is dependent on prior processing history, degree of strain hardening and other factors.

Attempts to utilize Inconel, a nickel base alloy, as a brazing material were not successful. T-joint specimens were prepared and brazed with Inconel at 2550° F. Nickel forms a brittle intermetallic phase with molybdenum and the joints did not exhibit any ductility. The literature [40] indicated that the formation of the brittle nickel-molybdenum phase could be eliminated by employing a chromium barrier between the braze and base alloy. However, this technique was not pursued, since Inconel as a braze material offered no advantages over Haynes 25.

A 48 Ti-48 Zr-4 Be alloy was prepared and evaluated for joining TZM. This alloy was developed by the Metallurgy Division of Oak Ridge National Laboratory. The alloy flows at approximately 2000° F in an inert atmosphere and it was selected initially for brazing in vacuum in an

attempt to attain a higher remelt temperature. Brazing tests conducted in vacuum indicated that rapid volatilization of the beryllium in this alloy system would raise the remelt temperature to approximately 3100° F. However, successful brazed joints were not obtained with the TZM alloy. The braze alloy did not exhibit good filleting and wetting characteristics and, as a result, poor joint strengths were obtained.

While only the high remelt temperature alloys of palladium are of interest, pure palladium was evaluated to determine if this base system would have any deleterious effects on TZM. As shown in Fig. 44, only slight alloying has occurred; the brazing temperature was 2900° F. From the results obtained, the high remelt temperature palladium base alloy systems should pose no adverse problems.

Unalloyed titanium was evaluated as a braze material for the molybdenum alloy heat shield panels. A T-joint and laminate of TZM brazed with titanium at 3100° F are shown in Figs. 45 and 46, respectively. An alloy zone is evident, but the zone is relatively narrow. A qualitative bend test indicated a ductile joint, but the base material exhibits very little ductility. A honeycomb panel was brazed with titanium (Fig. 47) and a typical core-to-skin joint is shown in Fig. 48. The core is extremely brittle and had to be handled carefully in order to section the panel. For this reason, it is hoped that a high remelt temperature braze alloy will prove satisfactory in later evaluation studies.

D-36 braze alloy evaluation. Four brazing materials have been evaluated for the D-36 columbium alloy (Table 7). Only T-joint and laminate specimens have been used for evaluation. Receipt of D-36 foil for honeycomb core is scheduled during the next quarter. The braze materials evaluated are a titanium-zirconium-beryllium alloy, pure palladium, palladium-copper and unalloyed titanium.

The TZB braze alloy (48 Ti-48 Zr-4 Be) developed very satisfactory brazements with D-36 at 2550° F. The alloy exhibited good filleting and wetting characteristics with the D-36 alloy, in direct contrast to the results obtained for TZM. A T-joint and laminate metallographic section are shown in Figs. 49 and 50, respectively. An alloy bond is evident, with some erosion of the base material (Fig. 49). The erosion of the base alloy is slight and considered acceptable. With the use of this braze alloy system, a remelt temperature of 3100° F is expected, although this has not been verified through tests. A test apparatus should be available early in the next quarter for determining remelt temperatures of the braze alloys under evaluation.

Pure palladium was evaluated as a brazing material. As shown in Fig. 51, the palladium has alloyed severely with the base material. Prior brazing experience with palladium in conjunction with unalloyed columbium and the D-31 (Cb-10 Ti-

TABLE 6
Summary of Braze Alloy Evaluation--TZM

<u>Base Alloy</u>	<u>Braze Alloy</u>	Brazing Temperature (°F)	<u>Remarks</u>
TZM	Haynes 25	2600	Excellent filleting and wetting. Brazed joint exhibits good ductility.
TZM	Inconel	2550	Excellent filleting and wetting. Brazed joint exhibits no ductility due to formation of a brittle inter- metallic phase.
TZM	Palladium	2900	Good filleting and wetting. Brazed joint exhibits good ductility. Base alloy is fully recrystallized.
TZM	48Ti, 48Zr, 4Be	2550	Poor filleting and wetting. No joint strength is evident due to poor wettability of braze alloy.
TZM	Commercially pure titanium	3100	Excellent filleting and wetting: The brazed joint exhibits some ductility but base alloy is extremely brittle.

TABLE 7
Summary of Braze Alloy Evaluation--D-36

<u>Base Alloy</u>	<u>Braze Alloy</u>	<u>Brazing Temperature (°F)</u>	<u>Remarks</u>
D-36	48Ti, 48Zr, 4Be	2550	Excellent filleting and wetting. Slight erosion of the base alloy occurs. Brazed joint exhibits good ductility.
D-36	Palladium	2900	Excellent filleting and wetting. Severe alloying and erosion of base alloy occur due to possible eutectic formation.
D-36	Commercially pure titanium	3100	Fair filleting and wetting. Braze joint exhibits good ductility. Severe erosion of base alloy occurs at temperatures above 3150° F.

10 Mo) alloy indicated no adverse effects. T-joint specimens were prepared and brazed with pure palladium at 2900° F to verify prior test results. Photomicrographs of these T-joints are shown in Figs. 52 and 53. Very little alloying or erosion is noted for the columbium-palladium brazement. However, some alloying and erosion of D-31 were obtained with pure palladium. In neither case is the alloying and/or erosion as severe as with the D-36-palladium combination. The D-36 alloy was also brazed with a 60 Pd-40 Cu alloy at 2250° F. Alloying and erosion of the parent material are evident, as shown in Fig. 54, although erosion and alloying are not as severe as in the case of the D-36-pure palladium brazement. The respective contributions of the copper and palladium to this behavior have not been determined.

Difficulties were also encountered with commercially pure titanium as a braze material. A T-joint of D-36 was initially brazed with titanium at 3100° F. However, the flow and filleting action of the braze material were not satisfactory (Fig. 55). The brazing temperature was increased to 3200° F, with time at temperature being constant. Examination of this brazed joint revealed that severe erosion of the base material had occurred (Fig. 56) as a result of the brazing temperature increase. It appears that the D-36 columbium alloy is sensitive to braze variations (filler alloy and temperature) normally considered tolerable for the columbium and columbium base alloys previously evaluated in our laboratories. Emphasis during the next quarter will be placed on developing satisfactory brazing alloys and techniques for the D-36 alloy.

E. MANUFACTURING PROCESS DEVELOPMENT

The purpose of this phase of the program is to develop the technology necessary to fabricate the brazed columbium and molybdenum honeycomb sandwich panels. This work includes forming, machining and welding of the D-36 columbium and TZM molybdenum. These metals require special handling and processing and do not lend themselves to standard manufacturing processes. State-of-the-art advances in manufacturing technology will be required. Manufacturing of TZM molybdenum and D-36 columbium honeycomb core and forming of the heat shield pans are two of the required developments.

1. Fabrication of Honeycomb Core

Three methods for fabricating the honeycomb core were evaluated. These differ primarily in the method of making the core node attachment. These methods are diffusion bonding, spike welding and electron beam welding. The diffusion bonding technique should develop into a very practical means of honeycomb core fabrication, but the present state of the art in diffusion bonding is not advanced to the degree where honeycomb cores of TZM or D-36 could be produced for this

program. Spike welding (high voltage, high current short duration impulse spot welding) was not successful on molybdenum foil.

A Hamilton-Zeiss electron beam welder was used to establish feasibility of electron beam welding TZM molybdenum. TZM foil (0.002 inch thick) was initially welded in this machine, and two 4 x 2.5 x 2.5 inch billets of 3/16-inch cell honeycomb core were fabricated (Fig. 59). A photomicrograph of a weld joint cut from one of these billets is shown in Fig. 60.

The electron beam welding technique was selected as the best available method of fabricating the TZM honeycomb core.

A new model, high voltage, Hamilton-Zeiss electron beam welder (Figs. 61 and 62) has just been installed. This model has a larger chamber and is capable of welding at speeds up to 100 inches per minute. After the machine is checked out and accepted, a study will be conducted to determine optimum weld settings and speeds. This new machine will be used to fabricate the TZM honeycomb core for the test panels.

As soon as D-36 columbium foil is available, a welding study will be made to evaluate the use of resistance welding and electron beam welding to fabricate honeycomb core. A resistance welding procedure similar to that shown in Fig. 62 could possibly be used.

A renite template (Fig. 58) was fabricated for use in inspecting the corrugated foil. A close check of the corrugated foil is necessary to assure that the axes of the corrugation are perpendicular to the edges of the foil. If the corrugations are not dimensionally correct, the nodes will become mismatched to such a degree somewhere in fabrication of the core billet that they cannot be joined.

The TZM and the D-36 foils will be cut into 18.5-inch lengths and corrugated in a special tool (Fig. 57). The corrugating tool was previously built for making stainless steel honeycomb. The corrugating rolls for a 3/16-inch square cell honeycomb core were reworked to allow for use with the 0.002-inch foil as required in the program. This reworked tool was used to corrugate the small quantity of TZM foil used to make the 4 by 2.5 by 2.5 inch billets.

2. Preparation of Honeycomb Core

After the honeycomb core is welded into a billet (14 by 14 by 4 inches), it is cut into slabs, which are then finished to the dimensions required. Three experimental methods were evaluated in an effort to establish the best method to slab and finish the honeycomb core. These methods were checked out on the two 4 by 2.5 by 2.5 inch TZM billets. The honeycomb core billet was first sawed into slabs with a commercial high speed band saw (10,000 surface feet per minute). After slabbing, the honeycomb core was finished

to the required dimension (± 0.0015 -inch tolerance). The three methods evaluated were:

- (1) A disc or mushroom-type cutter used to trim the core. This method of cutting caused tears in the core material and was abandoned.
- (2) Hand sanding of the core slab to the required dimension. As an alternate to this method, another slab or core was machine sanded. Both slabs were finished to the required dimensions.
- (3) A 4 by 2.5 by 2.5 inch honeycomb core billet filled with an acrylic plastic, then sawed and sanded. After the sanding operation the acrylic was removed with acetone.

A honeycomb core billet and a slab finished by each of these three methods are shown in Fig. 59. Both the second and third methods are capable of producing the required tolerances. The third method is the more accurate of the two, but also is the more time consuming. The second method, with the finishing accomplished by machine sanding, will be used in the program. If any problems develop with this method, the procedures noted in method (3) will be used.

3. Electron Beam Welding

A manufacturing process study was performed to establish the best configuration for the structural panel edge members. The edge members must be hermetically sealed to protect the uncoated honeycomb core from oxidation during high temperature exposure. Special attention is required in sealing the corner joints of the U-channel. The purposes of the manufacturing study were to determine a satisfactory corner configuration and to establish the matching tolerances required to electron beam weld the panel corners. A mitered corner joint was originally chosen in the test panel design study. The study indicated that a mitered corner joint was acceptable and could be welded if the channels were machined to within 0.002-inch tolerance. A picture of the U-channel frame which was welded in this study is shown in Fig. 64.

The edge member study was made with stainless steel, since neither TZM molybdenum nor D-36 columbium was available. Special care was used to be sure the study would be representative of what could be accomplished with the TZM and D-36.

A study was performed to determine if the electron beam welding technique could be used to seal around the periphery of the test panels. It is necessary to hermetically seal the panels and to protect the braze alloy from possible harmful effects from contact with the oxidation protection coating. The study consisted of taking two one-inch square pieces of material and brazing them together. After brazing, the electron

beam was passed around the edge of the specimen. This caused the refractory metal to melt and flow along the edge, sealing off the braze alloy. A photomicrograph of one of the test specimens is shown in Fig. 41.

F. PANEL TEST METHODS

Complete panel test procedures have not been formulated. Present plans require the testing of the flat panels in a picture frame shear jig and the curved panels in axial compression. The panels will be tested at elevated temperatures. Test temperatures will be determined after completion of the brazing study. The temperature selection will be based on strength of the braze alloys and the preliminary design studies.

1. Structural Panel Tests

The structural honeycomb panels will be heated in a quartz-lamp facility and loaded in shear and compression to failure. Special edge members will be welded to the shear panels so that the panels may be attached with special fasteners (refractory metal) to a test frame. The test methods study that is now in progress indicates that there are no insurmountable problems in accomplishing the planned tests.

The main area being given consideration is the welding of the shear test edge members to the TZM molybdenum panel. Studies by Hamilton Standard in the electron beam welding of molybdenum [44] report sufficient strengths and ductility to more than justify this test application.

Special test fixtures and load-applying equipment are necessary for the high temperature testing. During heating and cooling, the panels can expand and contract as much as 0.10 inch. The test fixtures and loading equipment must be designed so that the expansion and contraction can take place without thermal stress becoming high enough to cause the panel to fail. Current plans require the use of a special hydraulic test machine and superalloy test fixtures. In the shear test, the panels will be attached to the fixture with refractory metal bolts. The compression panels will be simply supported on the ends and sides.

2. Heat Shield Test

Original plans require cycling the heat shield test panels at elevated temperatures in order to establish their service capabilities. These plans at present remain unchanged, but a final method has not been selected for testing of the heat shield panels. Two facilities are available which could be used to test the heat shield panels. One of these is a quartz-lamp facility (Fig. 65) and the other is a hot-gas facility (similar but larger than that shown in Fig. 34). Both facilities have their advantages and disadvantages. A study is being conducted to determine which method will be most suitable for panel testing.

The heat shield panel will be supported on four flexible clips during testing. These clips will be welded to the back face of the panel. The other end of the support clip will be bolted to a water-cooled plate. This type of mounting system is representative of a typical vehicle application.

If the quartz-lamp facility is selected for testing the heat shield panels, a random progressive wave generator will be used to apply a sonic excitation to some of the panels. This sonic excitation will be applied in order to determine if the high frequency straining might cause failures in the brittle diffusion zone of the oxidation protection coatings. The hot-gas facility creates its own sonic noise field.

3. Small Specimen Tests

A high temperature cold-wall vacuum test furnace is being procured for testing material and honeycomb core properties. The furnace will have a chamber large enough to test beams and compression specimens, as well as tensile specimens, to a temperature of about 4000° F. The maximum test temperature planned for the program is at or about 3000° F. The furnace will be equipped so that stress-strain or load-deflection curves can be obtained at elevated temperatures. This furnace is not to be charged to this contract, inasmuch as it is expected to become a part of our regular laboratory equipment inventory.

The unfailed portions of all test panels will be cut into small specimens and tested in a vacuum furnace to determine the facing and honeycomb core properties. This testing will include:

	<u>Specimen Size (in.)</u>
(1) Column compression test	2 x 3
(2) Flatwise compression test	2 x 2
(3) Flexure beam test	2 x 10
(4) Shear beam test	2 x 6
(5) Tensile test of facing	1 x 7

III. CONCLUSIONS

Several conclusions can be drawn from the results and evaluations of the studies made in the program. The following general conclusions were formed:

- (1) The D-36 columbium and the TZM molybdenum alloys were selected for use in the program.
- (2) As soon as the stronger columbium alloys with higher strength-weight ratios become available in the thin foil and sheet forms, they should be considered for brazed honeycomb application.
- (3) Every attempt should be made to obtain a higher remelt temperature braze alloy for structural applications of TZM molybdenum alloy.
- (4) The electron beam technique is the best method available for welding TZM molybdenum. Electron beam welded joints in TZM honeycomb core have sufficient ductility to withstand the straining and vibrations of slabbing and sanding.

IV. PROGRAM MANAGEMENT

The program is currently in Phase I, with the braze alloy evaluation, manufacturing tool design, oxidation protection coating survey and the manufacturing methods studies now in progress. On these items, the program is proceeding according to schedule. The preliminary design and analysis and the materials survey have been completed.

The purchase orders for the TZM molybdenum and D-36 columbium are being delayed while the Material Specifications are negotiated with duPont and Universal Cyclops Steel Corporation. Since duPont is the sole source for the columbium, they have already started production of D-36. Universal Cyclops Steel Corporation was notified on 1 February 1962 that they were selected as the supplier for the TZM molybdenum. If Universal Cyclops Steel Corporation takes quick action on the purchase order, there should be no delay in the program schedule. Every effort will be made to assure that duPont and Universal Cyclops meet the delivery schedules.

In July 1961, our laboratory started an in-house program to develop methods of application

and to evaluate the Al-Sn coating for molybdenum. The main attractions of this coating were its reported ability to protect the specimen edges and the simplicity of applying the coating. Test results indicate that the Al-Sn coating system provides acceptable protection to 3000° F.

Every effort will be made to develop a high remelt temperature braze alloy for the structural molybdenum application, but it is not believed to be consistent with the objectives of the program to jeopardize the schedule or make any excessive expenditures in these attempts.

Because of the high cost of the refractory metals, every effort will be made in fabrication of the test panel details to keep the number of rejects to a minimum. Where possible, all rejected parts will be reworked to acceptable tolerances. The material from the rejected parts will be used to determine material property data, to check braze alloy strengths, and to evaluate the effects of oxidation protection coatings on the tensile properties of the refractory metals.

V. FUTURE WORK

Work during the next quarter will be concentrated in the following areas:

- (1) Selection of the oxidation protection coating.
- (2) Completion of the braze alloy evaluation study.
- (3) Fabrication of all tools necessary for forming, machining and welding of test panel details.
- (4) Complete formulation of test procedures and initiation of fabrication of test fixtures.
- (5) Establishment of all necessary manufacturing procedures.

VI. REFERENCES

1. Houch, J. A., "Physical and Mechanical Properties of Commercial Molybdenum-Base Alloys," Defense Metals Information Center, DMIC Report 140, Columbus 1, Ohio, November 30, 1960.
2. "Physical and Mechanical Properties of Columbium and Columbium-Base Alloys," DMIC Report No. 125, February 1960.
3. "High-Temperature Fasteners," Contract AF33(616)-8104, Republic Aviation Company, ESRD7-4 and ESRD7-7 Quarterly Reports, September 10, 1961.
4. Refractomet Division, Universal-Cyclops Steel Corp., Molybdenum Specifications, Mill Products, March 20, 1961 to November 28, 1961.
5. Gentry, W. O., and Michael, A. B., "Properties of Some Columbium-Rich Alloys in Columbium-Tantalum-Tungsten-Zirconium System," Fansteel Metallurgical Corp., North Chicago, Ill., April 26, 1961.
6. "Refractory Metal Structural Development Program," Part I--Refractory Metal and Development, Part II--Coating Studies and Application, Contract No. AF33(616)-6578, Project Nos. 1368 and 7381, Task No. 13719 and 73810, McDonnell Aircraft Corporation, General Electric Company.
7. "Research on Workable Refractory Alloys of Tungsten, Tantalum, Molybdenum and Columbium," Crucible Steel Company of America, Central Research Laboratory, Cambridge, Mass., WADC TR 61-134, May 1961.
8. Lement, B. S., Thomas, D. A., Weissmann, S., and others, "Substructure and Mechanical Properties of Refractory Metals," Manufacturing Laboratories, Inc., Cambridge, Mass., WADC TR 61-181, August 1961.
9. Semchyshen, M., and Barr, R. Q., "Extrusion and Mechanical Properties of Some Molybdenum- and Tungsten-Base Alloys," Climax Molybdenum Company of Michigan, ASD TR 61-193, June 1961.
10. Climax Molybdenum Corp., Molybdenum-0.5Ti and TZM Alloys Specifications.
11. E. I. duPont deNemours, D-14, D-31 and D-36 Alloys Data Sheets, 1961.
12. Private Communications--Fansteel Metallurgical Corp., FS-82 Alloy.
13. Westinghouse Electric Corp., B-33, B-66 and B-77 Alloys, Data Sheets.
14. Haynes Stellite Company, Haynes Refractory Metal and Alloys, October 1961.
15. Suggested High Strength TZM Specification, Climax Molybdenum Corporation, August 21, 1961.
16. Private Communications--Haynes Stellite Company, Cb-752.
17. Barr, R. Q., and Semchyshen, M., "Stress-Strain Curves for Wrought Molybdenum and Three Molybdenum-Base Alloys," Climax Molybdenum Company, New York, N. Y., December 1959.
18. Timoshenko, S., and Woinowsky-Krieger, S., "Theory of Plates and Shells," McGraw-Hill, p 49, 1959.
- 18a. Nadai, A., "Theory of Flow and Fracture of Solids," McGraw-Hill, pp 383 to 387, 1950.
19. Swann, R. T., "Calculated Effective Thermal Conductivities of Honeycomb-Sandwich Panels," NASA TR D-171, December 1959.
20. Swann, Robert T., Pittman, Claud M., "Analysis of Effective Thermal Conductivities of Honeycomb and Corrugated-Core Sandwich Panels," NASA TR D-714, April 1961.
21. Dukes, W. H., Gosden, G. E., Kappelt, G. F., and Mirti, A. E., "Manufacturing Methods for Insulated and Cooled Double-Wall Structures," Final Technical Engineering Report ASD TR 61-7-799, AF33(600)-40100, May 1961.
22. Jefferys, R. A., and Gadd, J. D., "Development and Evaluation of High Temperature Protective Coatings for Columbium Alloys," Part I--Coating Development, ASD TR 61-66, Part I May 1961, Part II June 1961.
23. Krier, C. A., "Coatings for the Protection of Refractory Metals from Oxidation," DMIC Report 162, November 24, 1961.
24. "Review of Recent Developments on Oxidation-Resistant Coatings for Refractory Metals," DMIC Memorandum No. 120, July 31, 1961.
25. Chao, P. J., Payne, B. S., Jr., and Priest, D. K., "Development of a Cementation Coating Process for High-Temperature Protection of Molybdenum," Contract No. AF33(616)-7192, ASD TR 61-241, June 1961.
26. "Elevated-Temperature Mechanical Properties and Oxidation Resistance of Columbium and Its Alloys," DMIC Memorandum No. 8, February 4, 1959.

- 27. "Coatings for the Protection of Refractory Metal from Oxidation," DMIC Report No. 162, November 24, 1961.
- 28. "Review of Recent Developments on Oxidation-Resistant Coatings for Refractory Metals," DMIC Memorandum No. 137.
- 29. Chao, P. J., Zupan, J., and Priest, D. K., "Recent Development of Oxidation-Resistant Coating of Pfaudler," PF61-15, July 14, 1961.
- 30. Lawthers, D. D., and Sama, L., "Aluminide and Beryllide Protective Coatings for Tantalum," Sylcor Division, Sylvania Electric Products, Inc., April 26, 1961.
- 31. Lawthers, D. D., and Sama, L., "High Temperature Oxidation-Resistant Coatings for Tantalum-Base Alloys," Sylcor Division, Sylvania Electric Products, Inc., ASD TR 61-233 Contract No. AF33(616)-7462, Project No. 7351, Task No. 73512.
- 32. Aves, W. L., Jr., Bourland, G. W., Featherston, A. B., Forcht, B. A., and O'Kelly, K. P., Vought Astronautics Division, Chance Vought Corp., "Diffusion Coating Process for Columbium-Base Alloys," Contract No. AF33(616)-7896, August 1961.
- 33. Jefferys, R. A., and Gadd, J. D., "Development and Evaluation of High Temperature Protective Coatings for Columbium Alloys, Part II--Coating Evaluation, Thompson-Ramo-Wooldridge, Inc., Contract No. AF33(616)-7215, June 30, 1961.
- 34. National Symposium on Ceramics and Composites, Coatings and Solid Bodies, Society of Aerospace Materials and Process Engineers, Dayton, Ohio, November 14 and 15, 1961.
- 35. Anthony, F. M., "Design Fabrication and Testing of a Molybdenum Alloy Outer Wall Heat Shield," Dallas, Texas--Refractory Composites Working Group, August 8 to 10, 1961.
- 36. "Coatings for the Refractory Metals," Materials in Design Engineering, 129, November 1961.
- 37. Weare, N. E., and Monroe, R. E., "Welding and Brazing of Molybdenum," DMIC Report 108, March 1, 1959.
- 38. Pattee, H. E., and Evans, R. M., "Brazing for High-Temperature Service," DMIC Report 149, February 21, 1961.
- 39. Development of Low Temperature Brazing of Tungsten for High Temperature Service, Solar Aircraft Company, Interim Reports 1, 2 and 4 prepared under Navy Bureau of Naval Weapons Contract No. 61-0414-c.
- 40. Bredzs, N., Ruoy, J., and Schwartzbart, H., "Development of Partially Volatile Brazing Filler Alloys for High Temperature Applications and Resistance to Oxidation," WADD TR 59-404, Part II, June 1961.
- 41. Kearns, W., Clark, J., Young, W., and Jones E., "Investigation of the Physical Metallurgy of Joining Tungsten and Columbium," Quarterly Report No. 3, Contract AF 33(616)-7484, April 10, 1961.
- 42. Armstrong, R., "Exo-Reactant Nickel Base Structural Adhesives," Quarterly Progress Report No. 3 prepared under Navy Bureau of Naval Weapons Contract Now61-0308-c, October 1961.
- 43. Hansen, Max, "Constitution of Binary Alloys," McGraw-Hill Book Company, 2nd Edition, 1958.
- 44. Hokanson, H. A., Kern, W. I., "Electron Beam Welding of Tungsten and Molybdenum," Hamilton Standard Division, United Aircraft Corp., ASD, Contract AF 33(616)-7439, Task No. 73516, Preliminary Report, August 1961.

APPENDIX A
ILLUSTRATIONS

ER 12249

Form: Sheet Condition: Stress Relieved Except as Noted

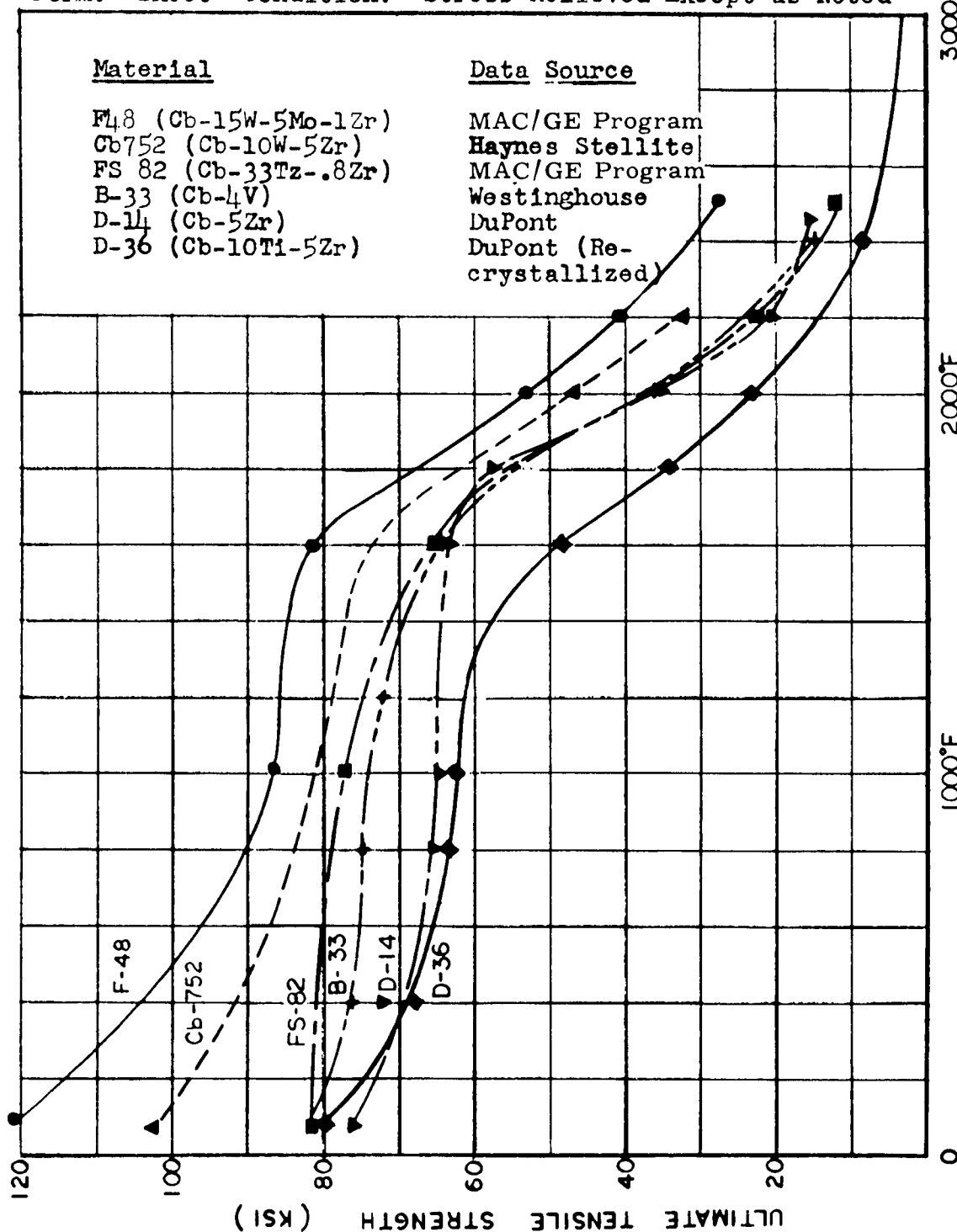


Fig. 1. Ultimate Tensile Strength Versus Temperature--Selected Columbium Alloys

Form: Sheet Condition: Stress Relieved Except as Noted

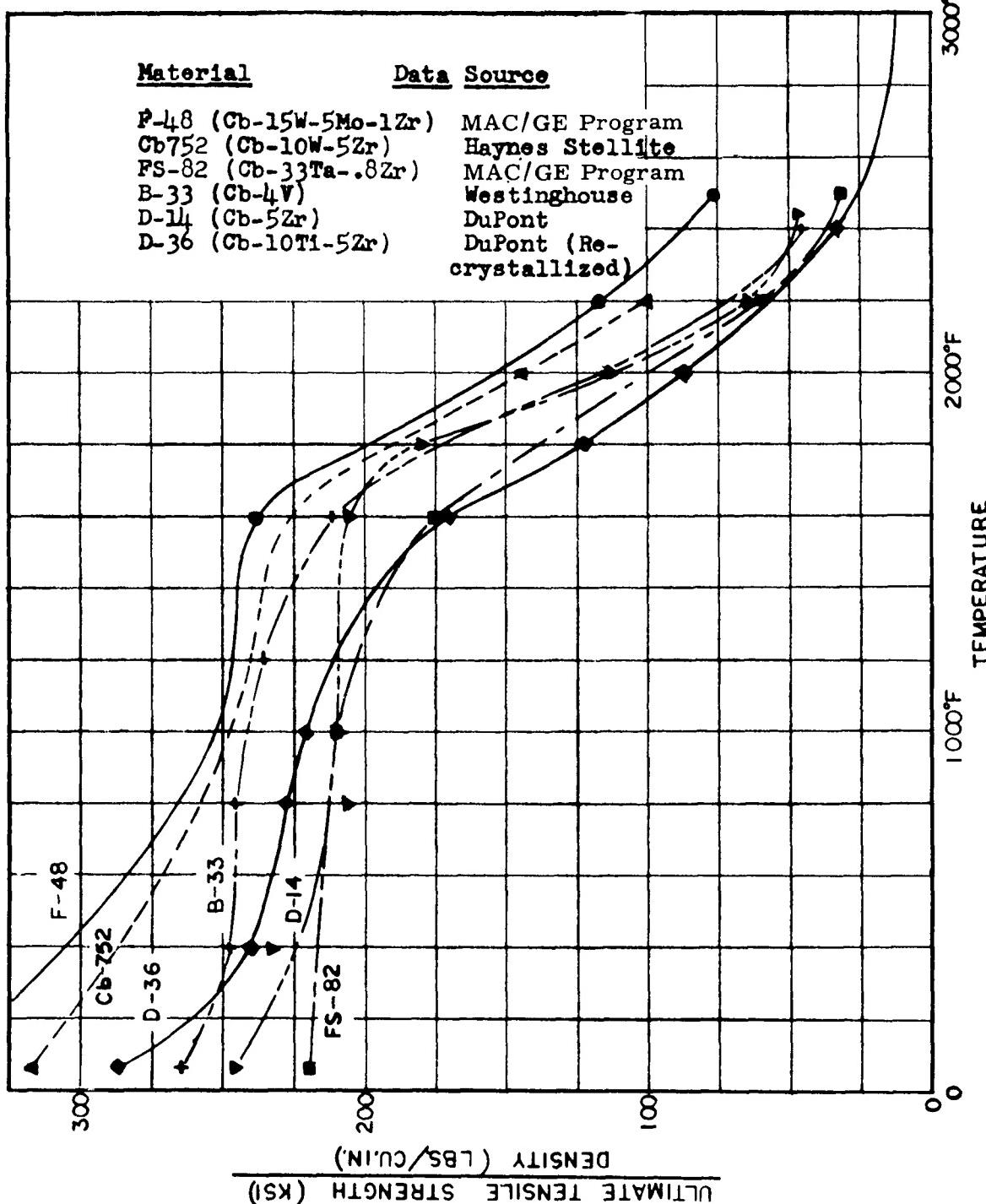


Fig. 2. Strength/Density Versus Temperature--Selected Columbium Alloys

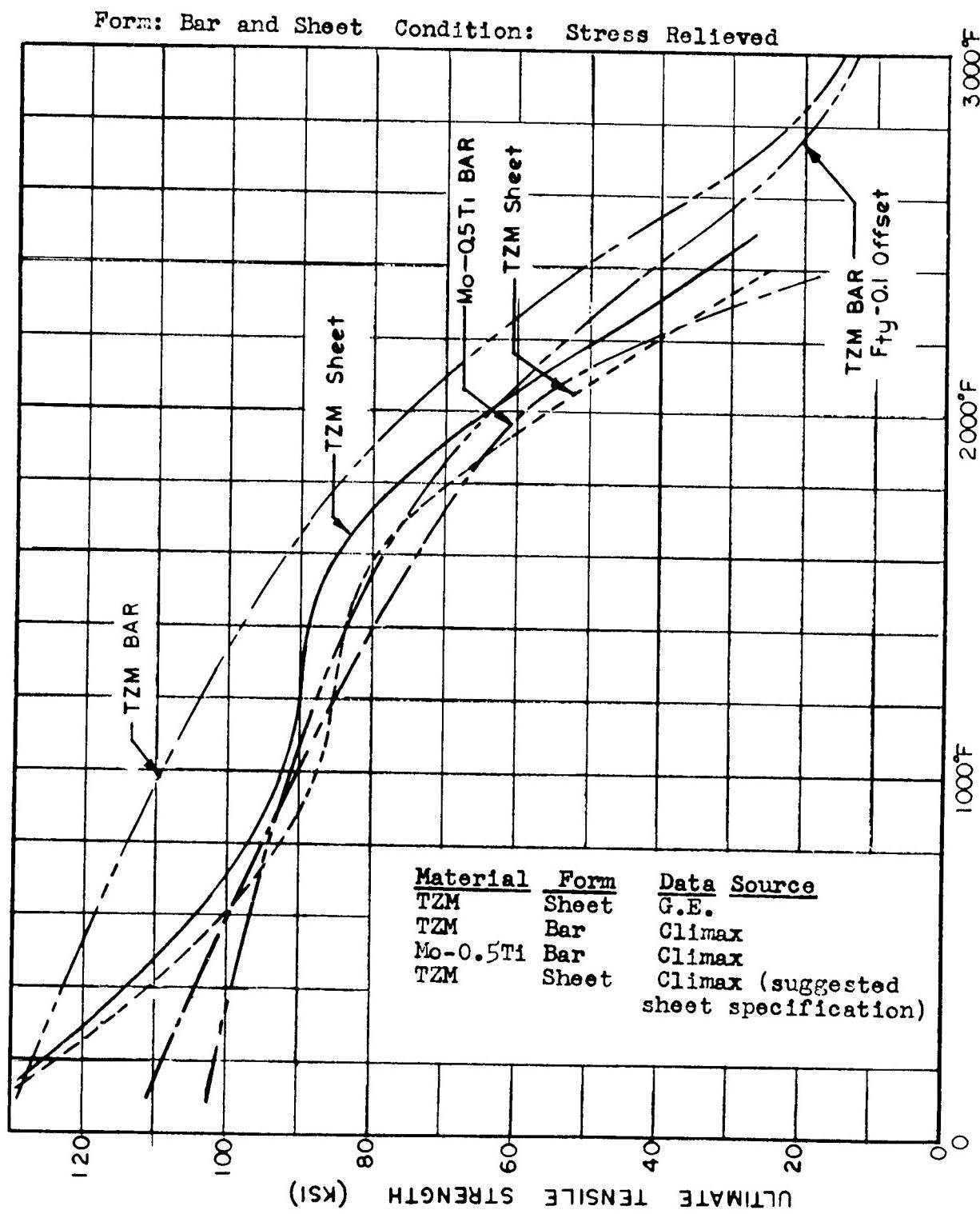


Fig. 3. Ultimate Tensile Strength Versus Temperature--Selected Molybdenum Alloys

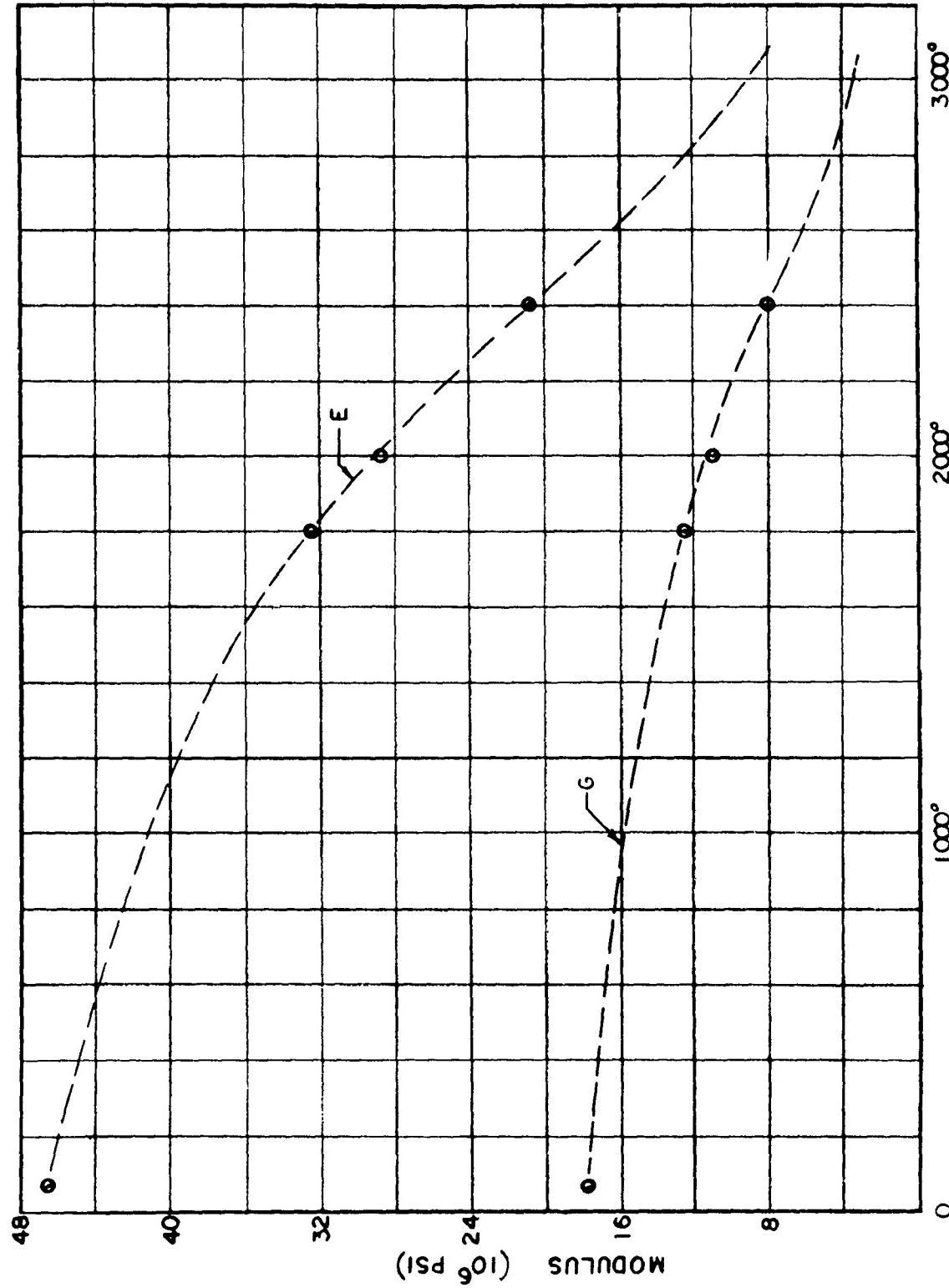


Fig. 4. TZM Molybdenum--Modulus of Elasticity and Modulus of Rigidity at Temperature

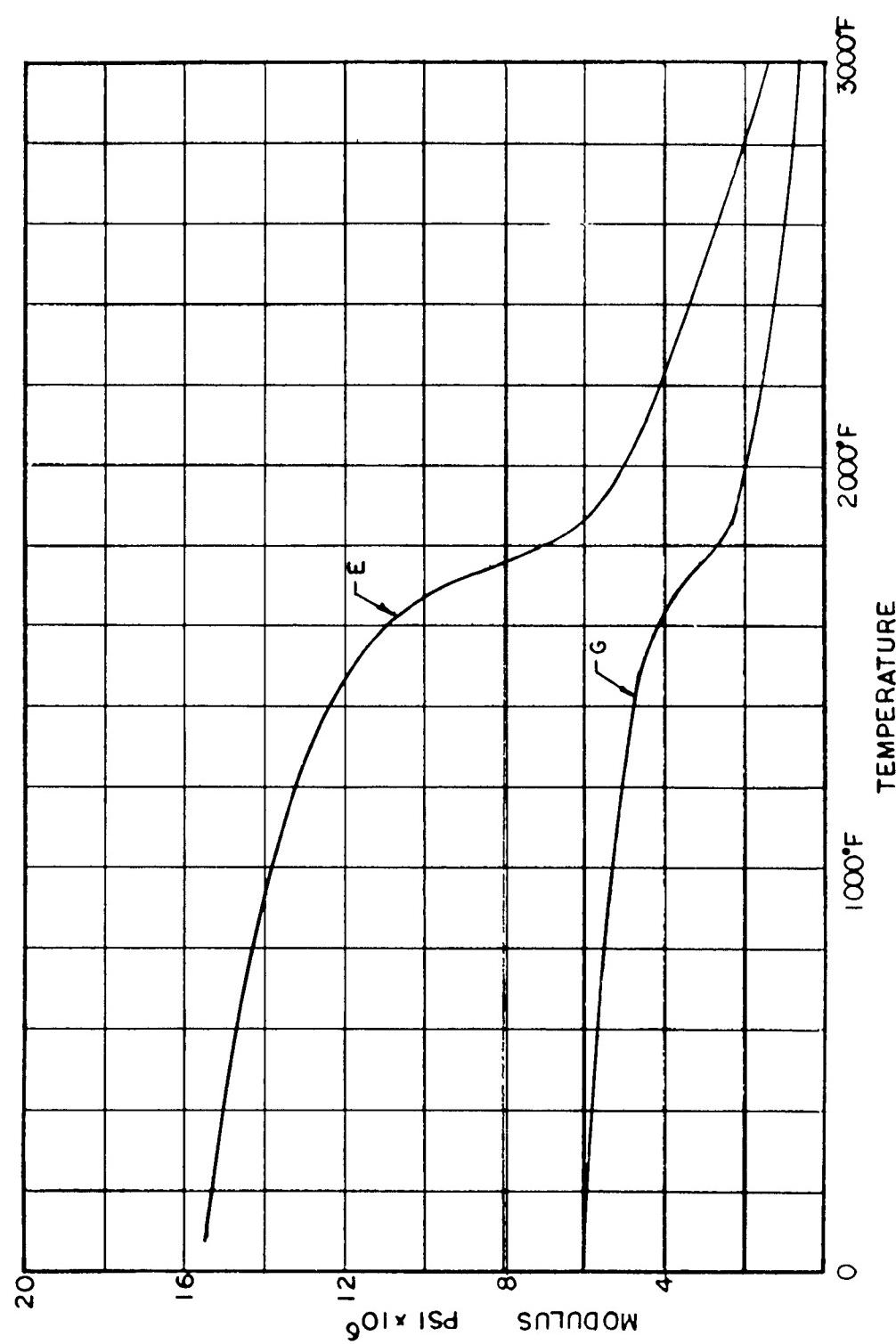


Fig. 5. D-36 Columbium--Modulus of Elasticity and Modulus of Rigidity at Temperature

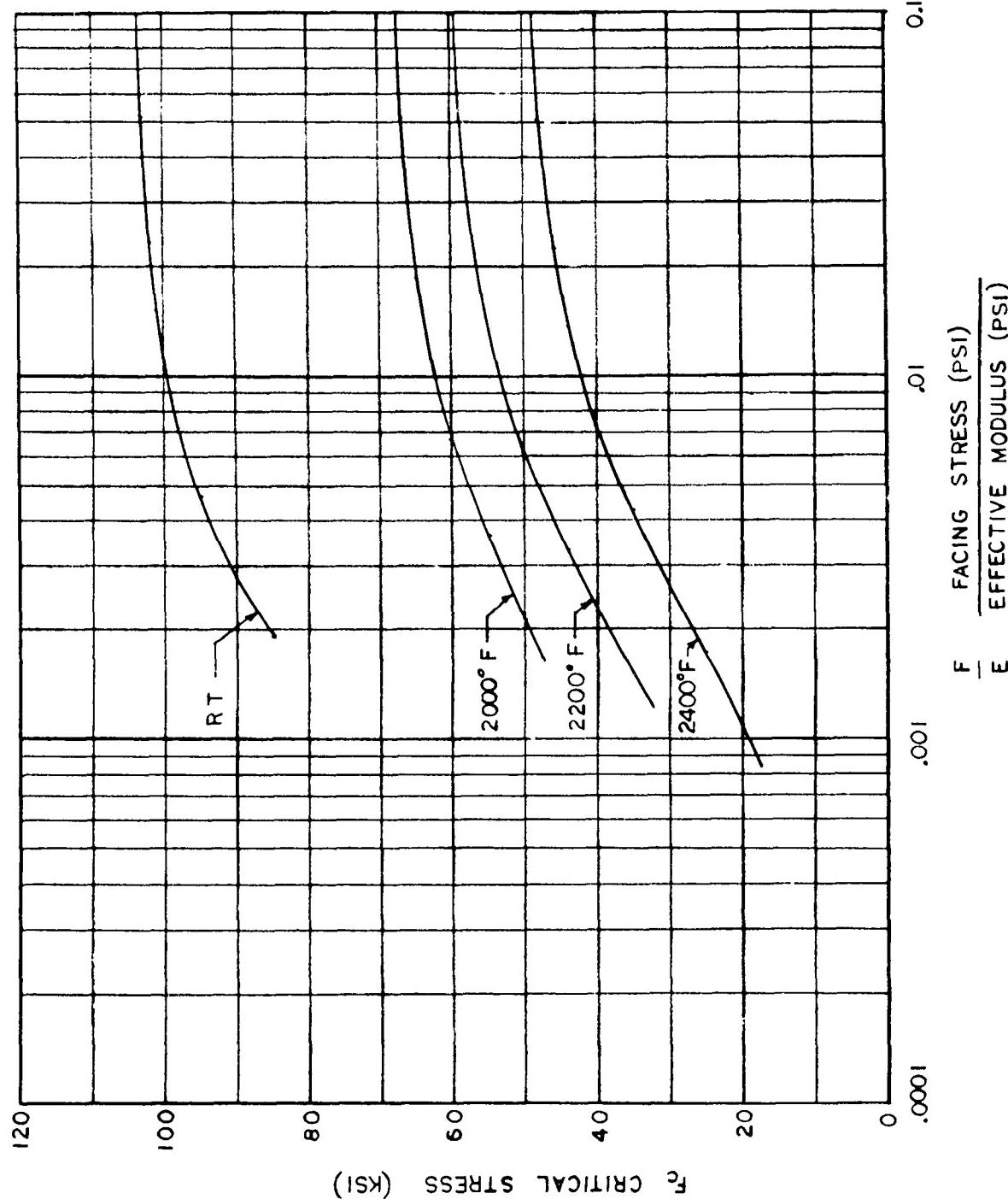


Fig. 6. Plasticity Correction Curve--TZM Molybdenum Alloy--Room Temperature and Elevated Temperature

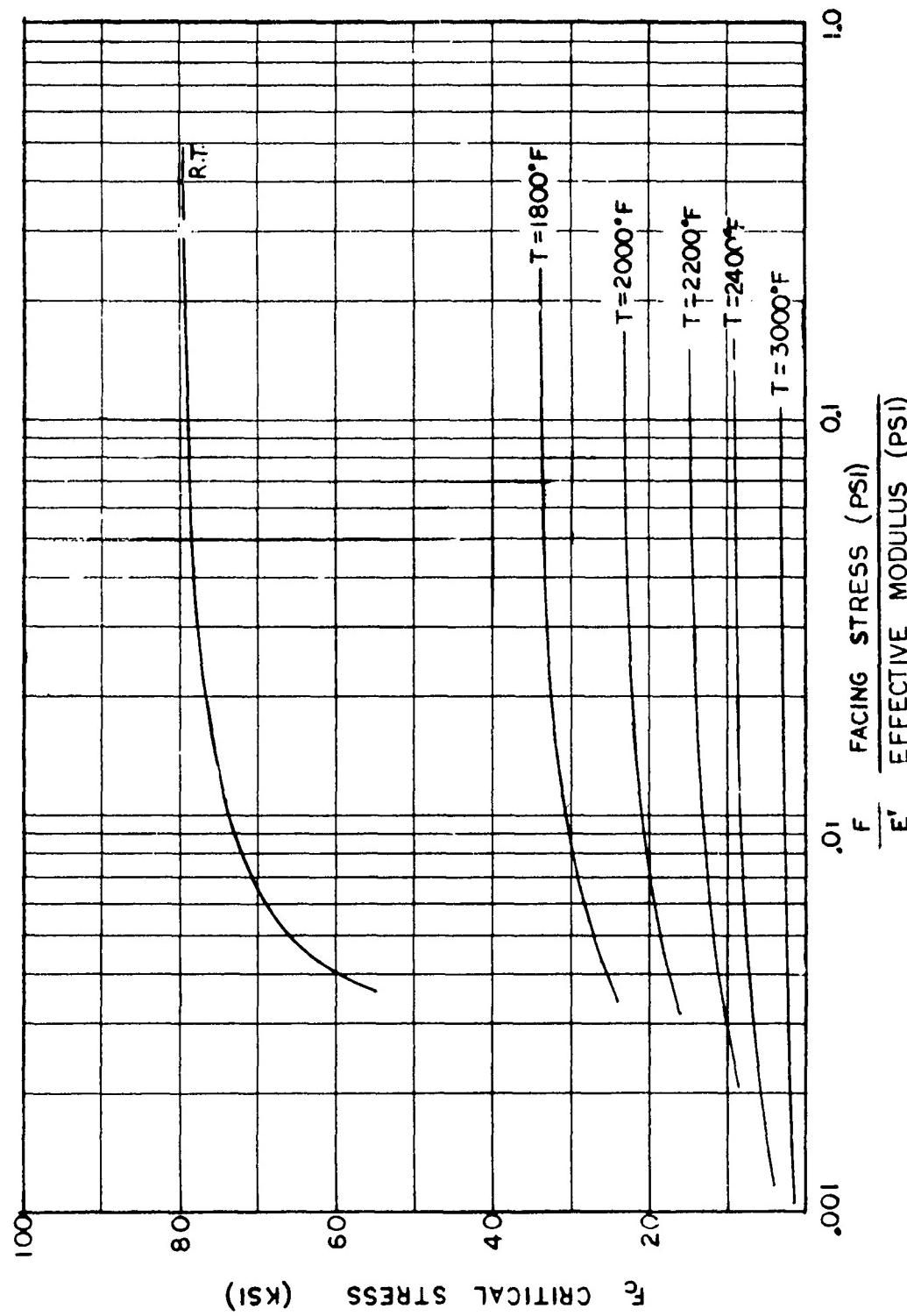


Fig. 7. Plasticity Correction Curve--D-36 Columbium Alloy--
Room Temperature and Elevated Temperature

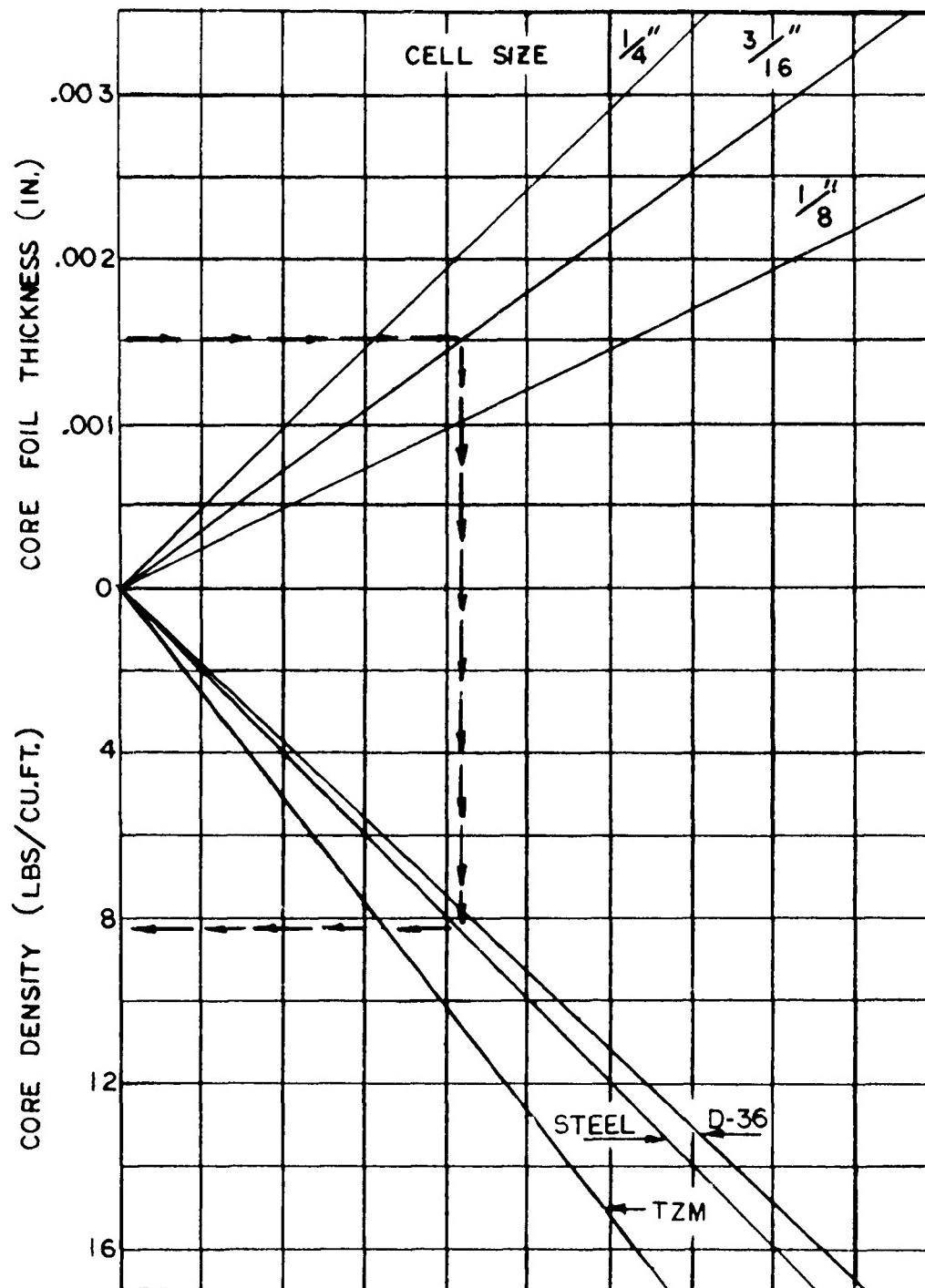


Fig. 8. Honeycomb Core Density for Various Core Thicknesses, Cell Sizes and Materials

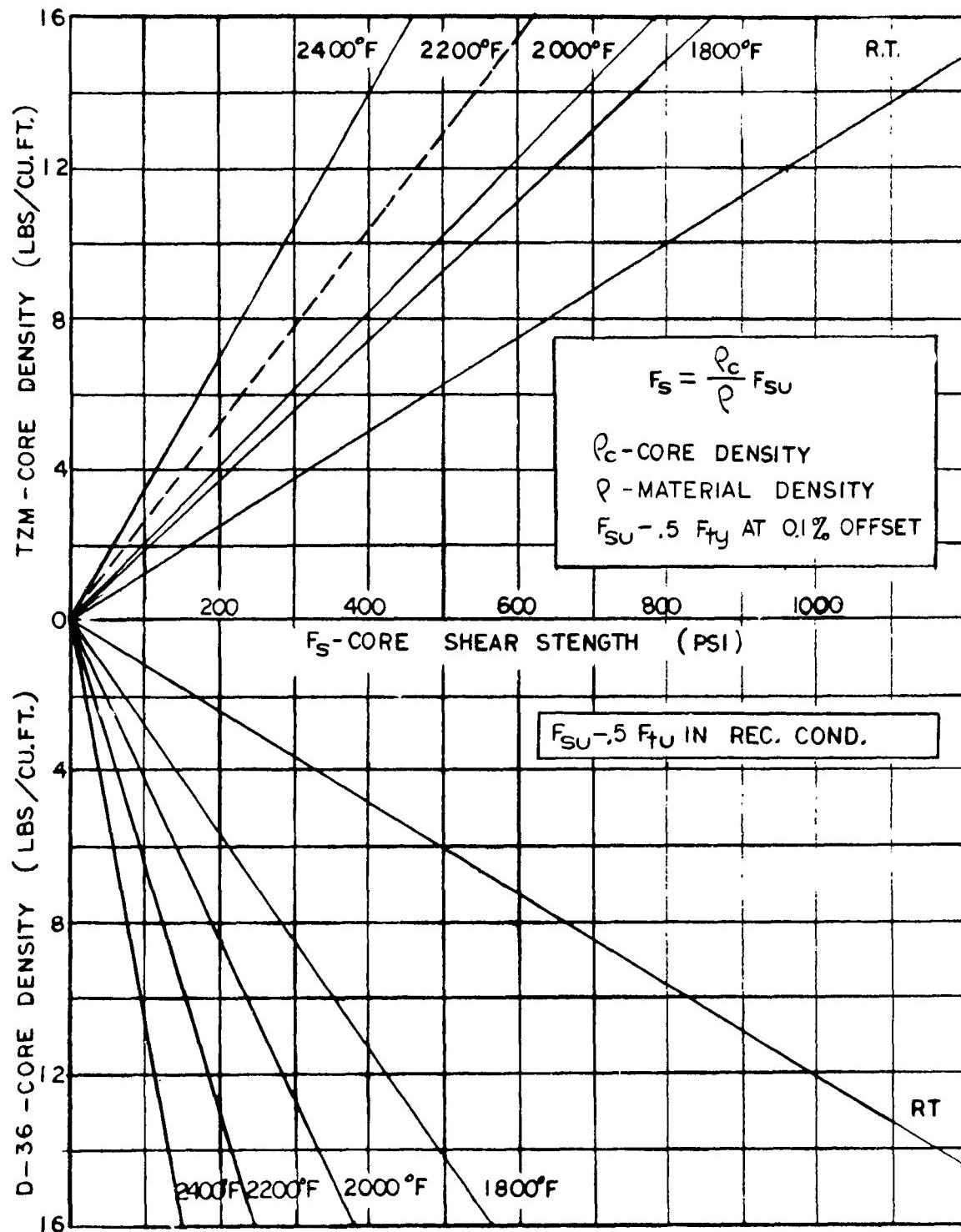


Fig. 9. Honeycomb Core Shear Strengths

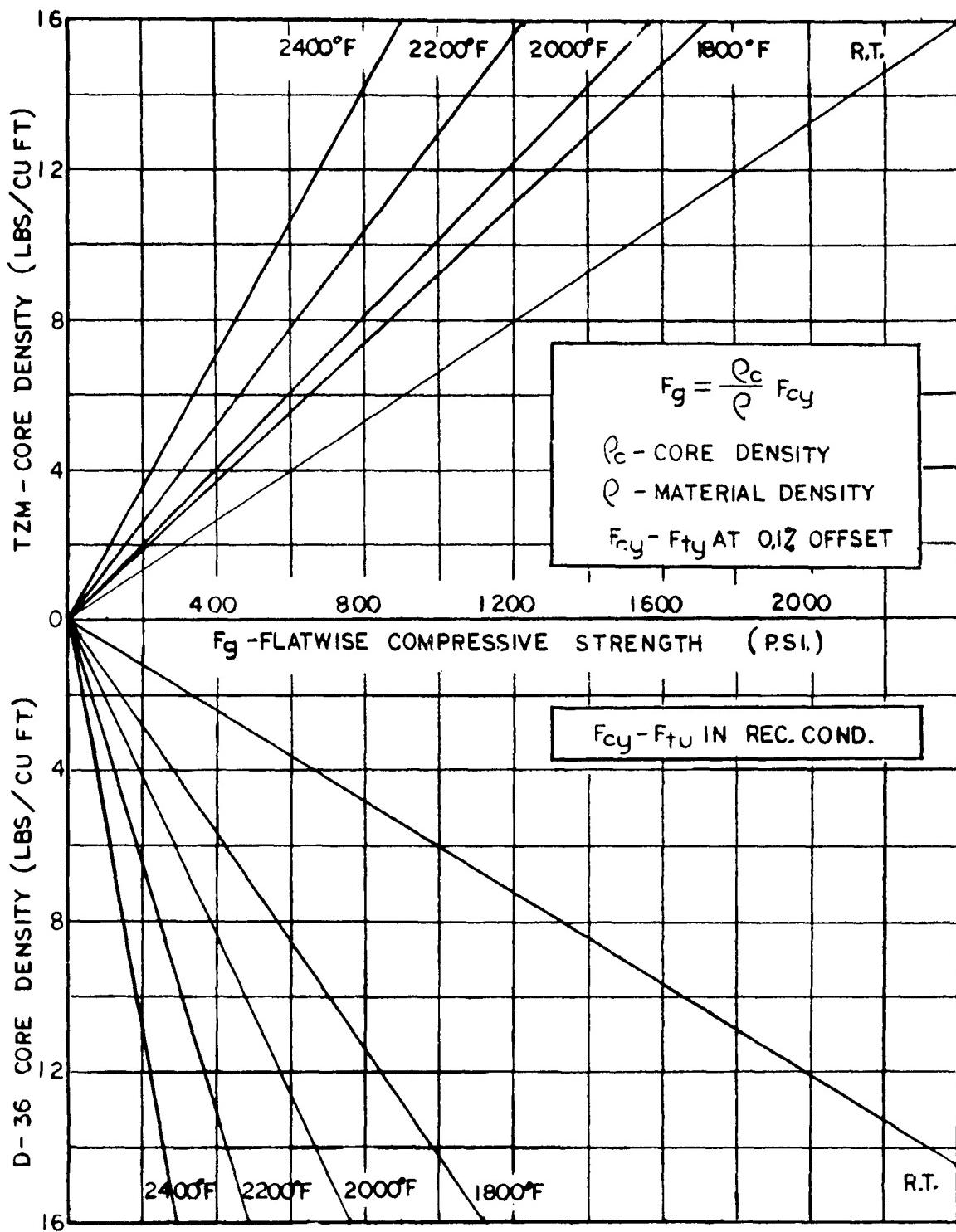


Fig. 10. Honeycomb Core Flatwise Compressive Strength

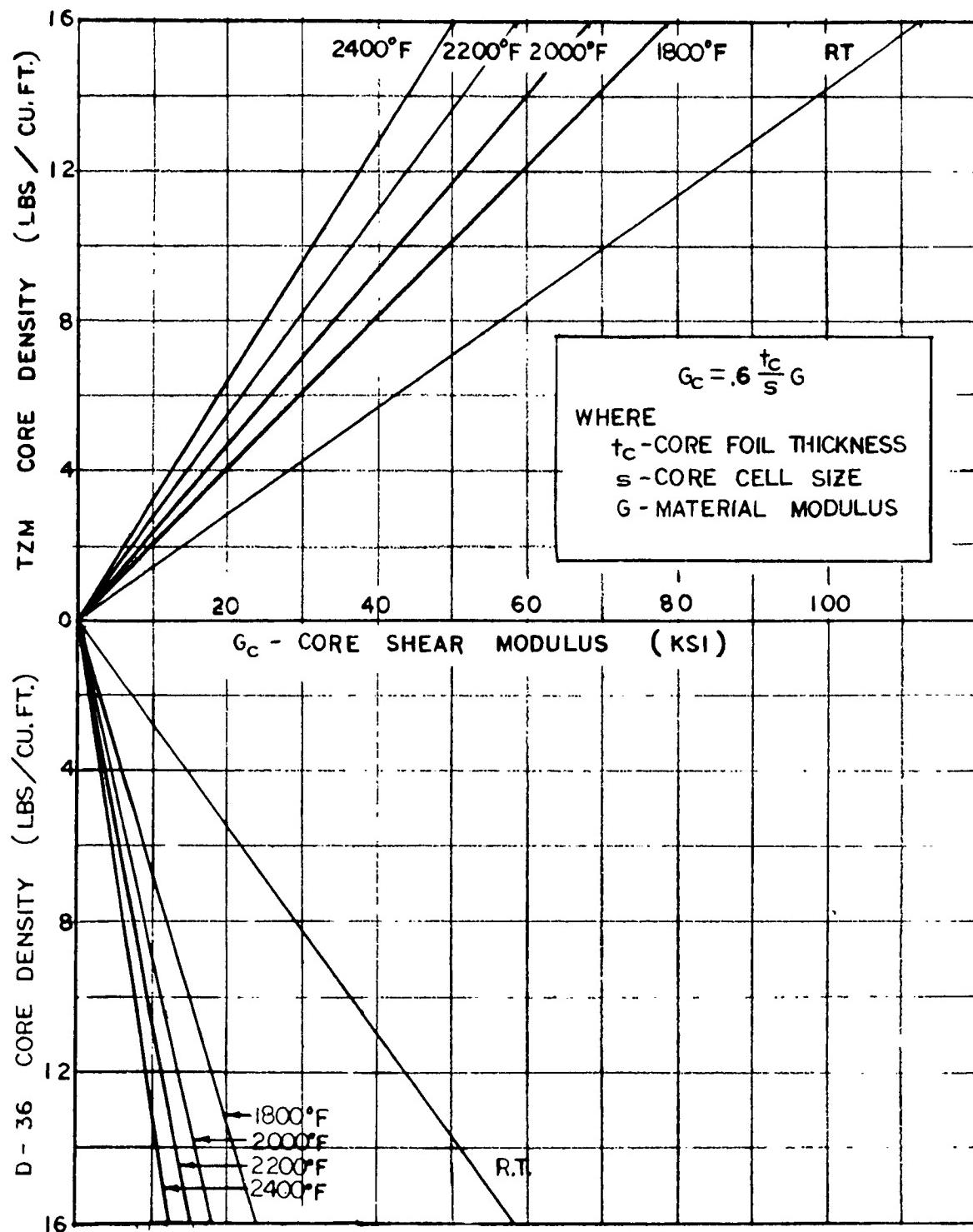


Fig. 11. Honeycomb Core Shear Modulus

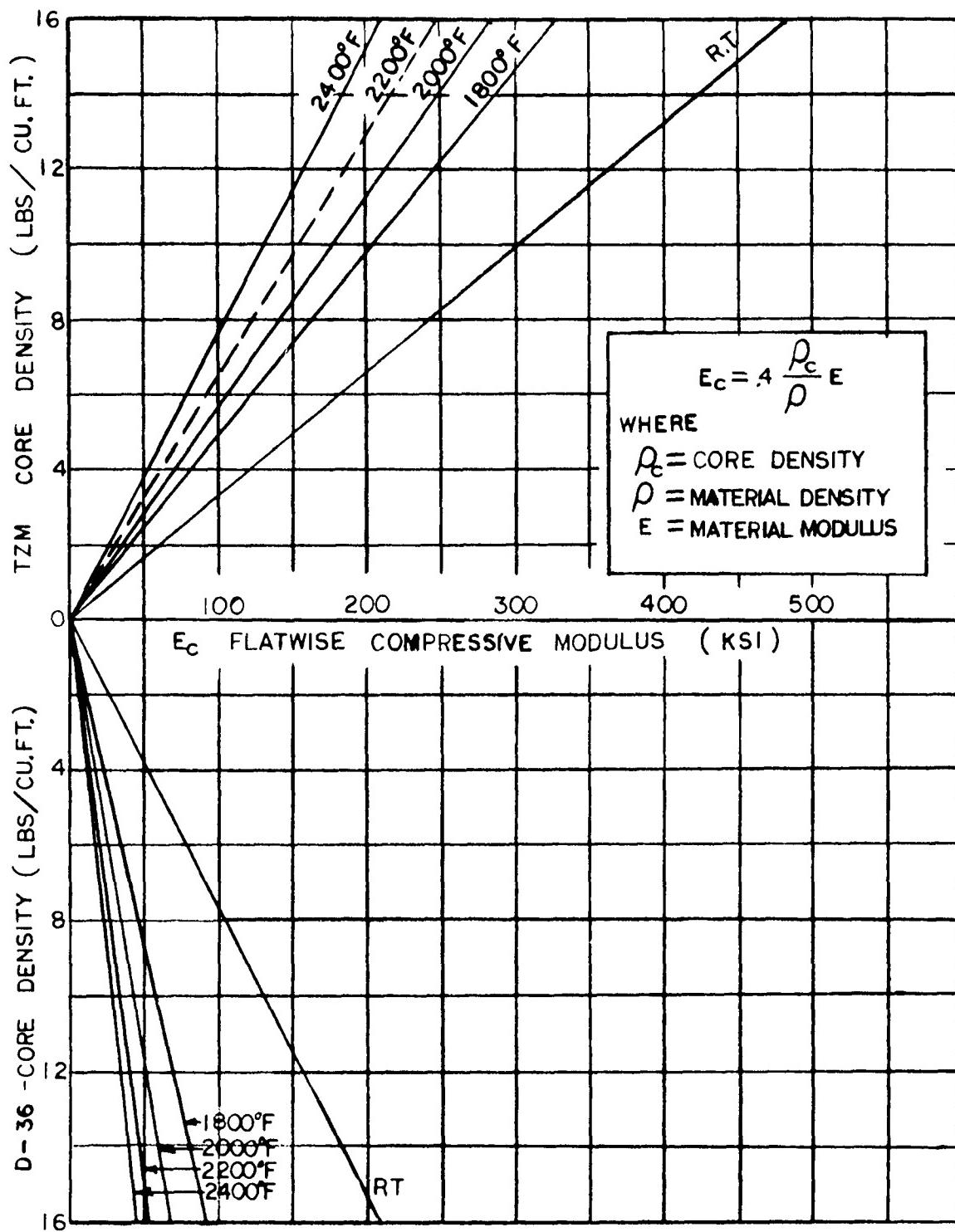
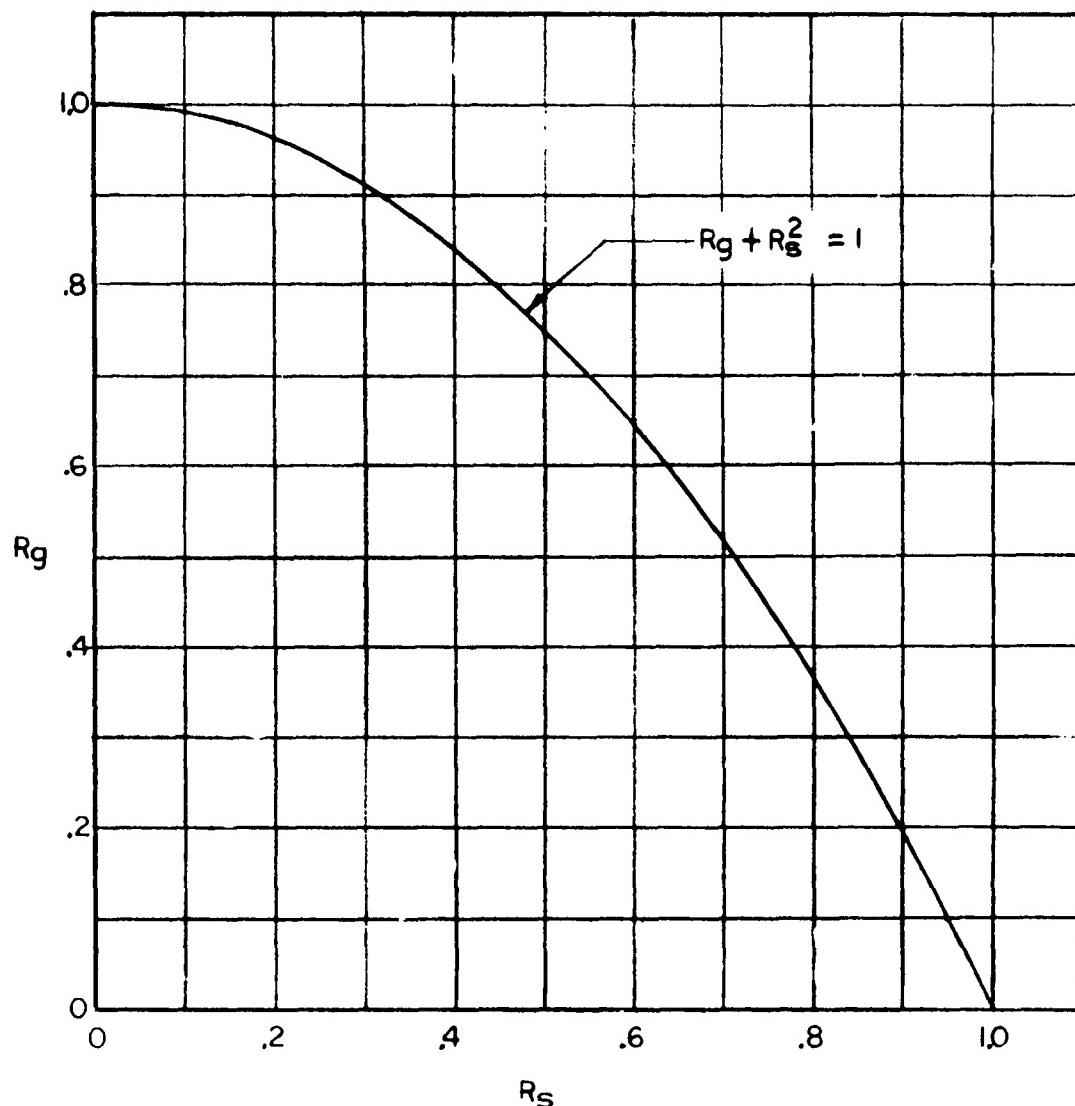


Fig. 12. Honeycomb Core Flatwise Compressive Modulus

The following interaction equation and curve are recommended for use with the honeycomb core.

$$R_g + R_s^2 = 1$$



where

$$R_g = \frac{\text{Applied core normal stress}}{\text{Allowable core normal stress}} = \frac{f_g}{F_g}$$

$$R_s = \frac{\text{Applied core shear stress}}{\text{Allowable core shear stress}} = \frac{f_s}{F_s}$$

Fig. 13. Core Strength Under Combined Loads

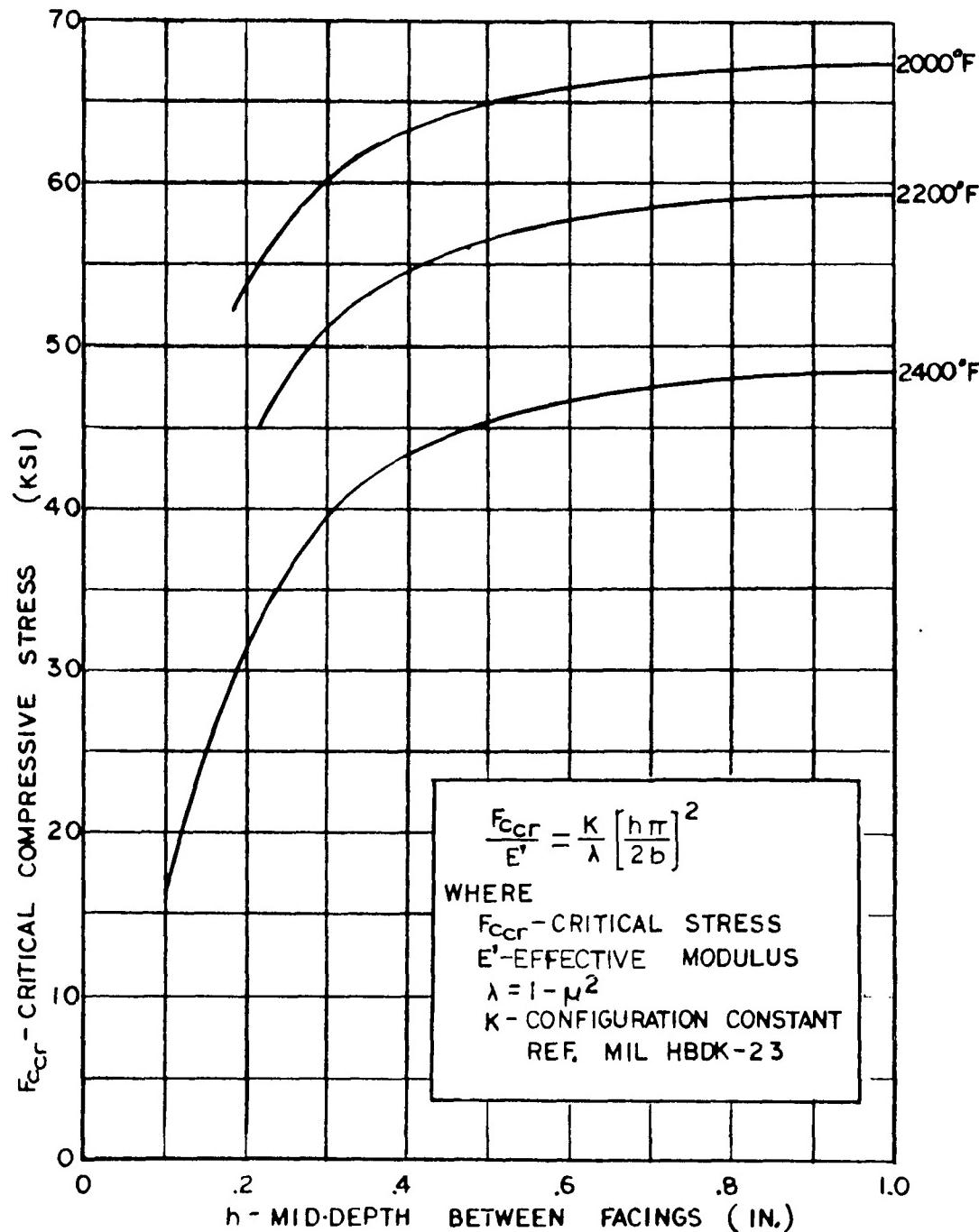


Fig. 14. Test Panels Critical Compressive Buckling Stress--TZM Molybdenum

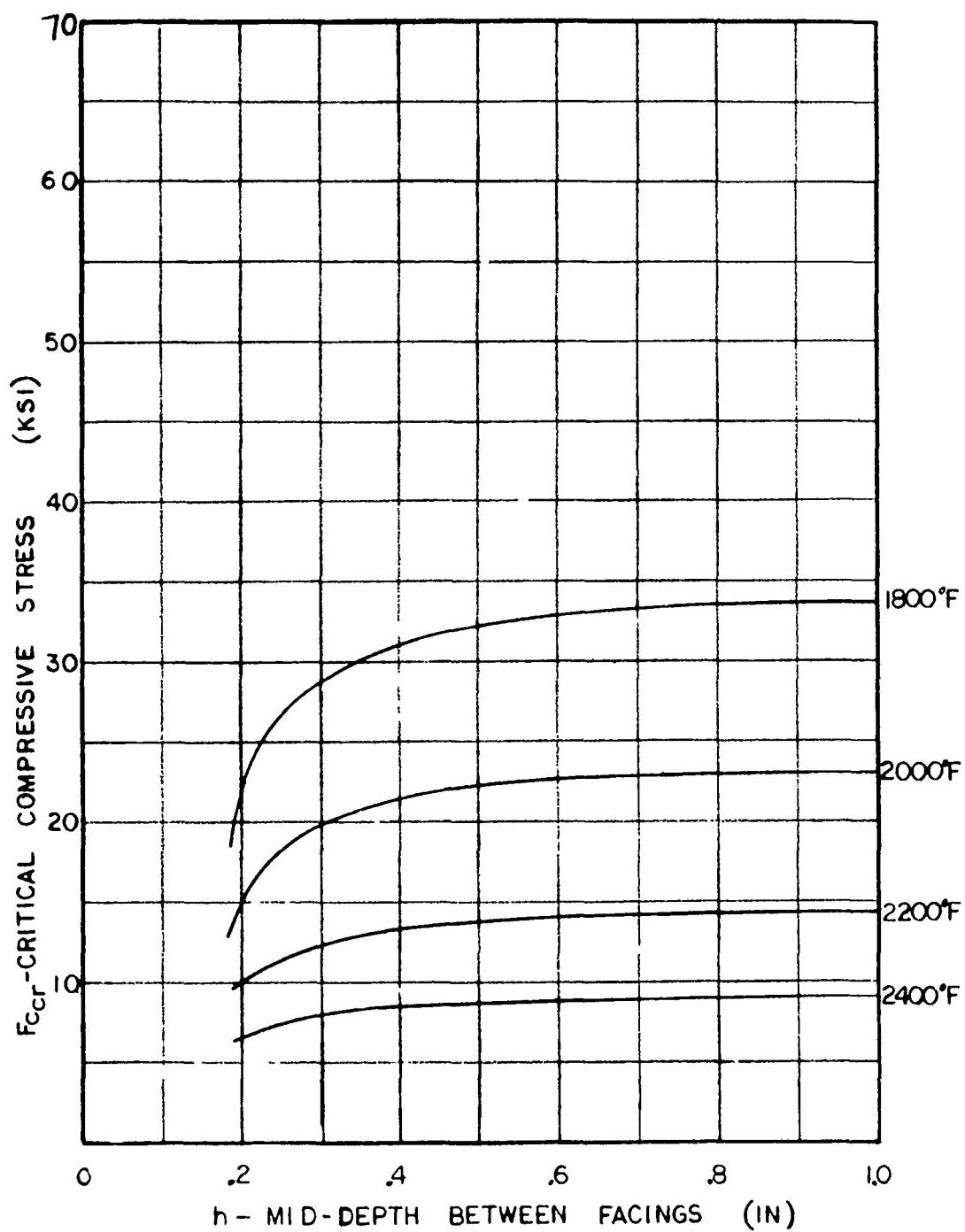


Fig. 15. Test Panels Critical Compressive Buckling Stress--D-36
Columbium

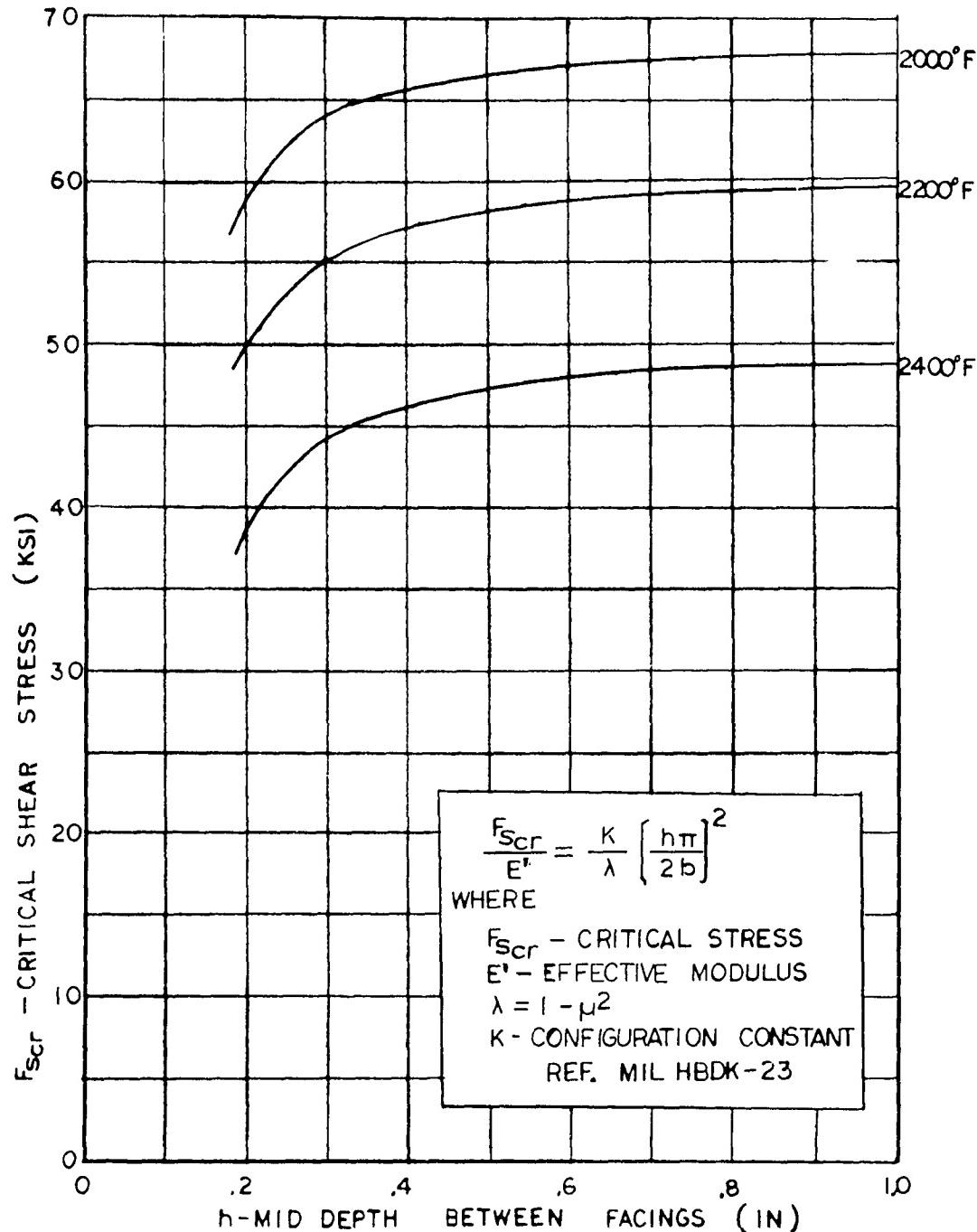


Fig. 16. Test Panel Critical Shear Buckling Stress--TZM Molybdenum

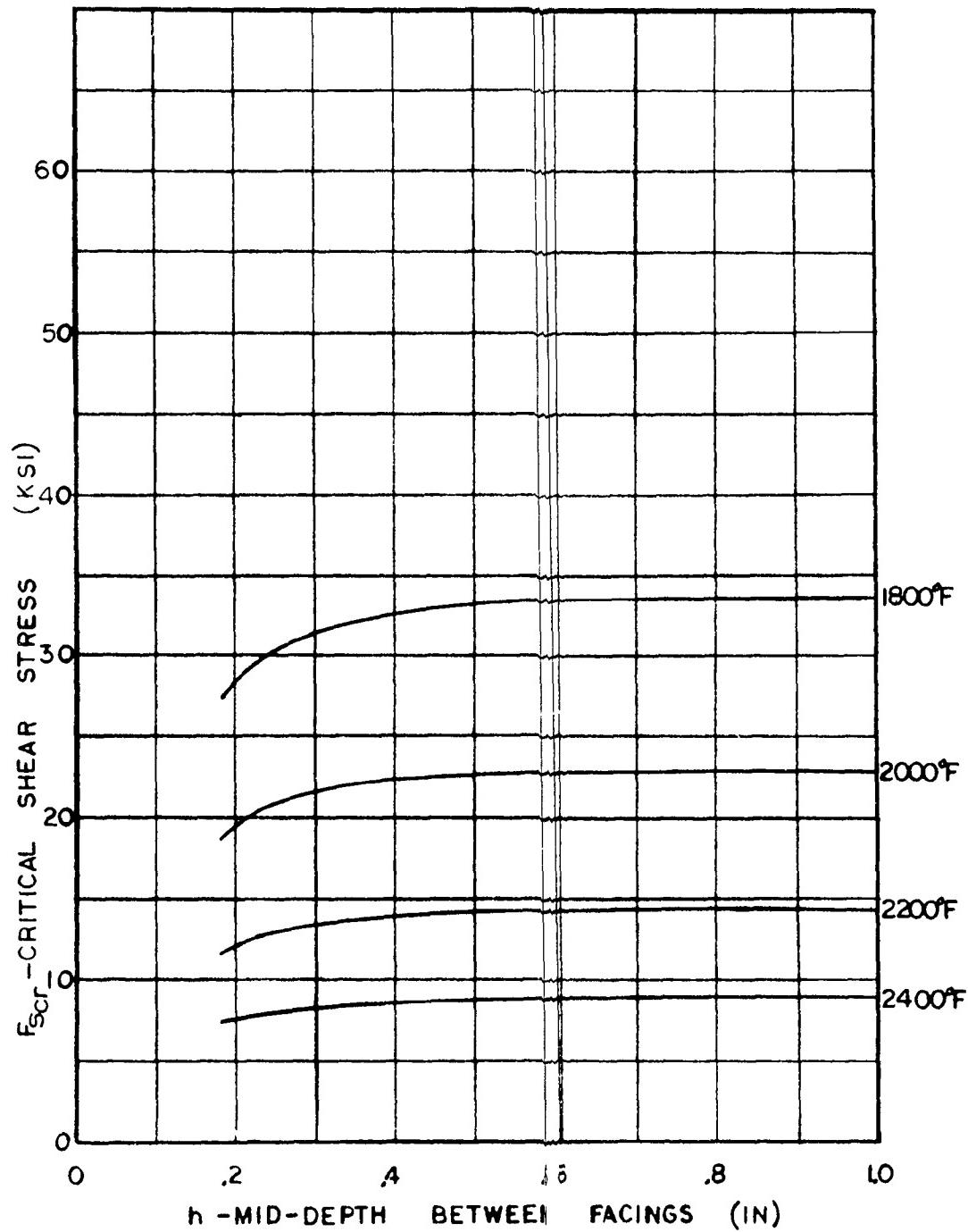


Fig. 17. Test Panel Critical Shear Buckling Stress--D-36 Columbium

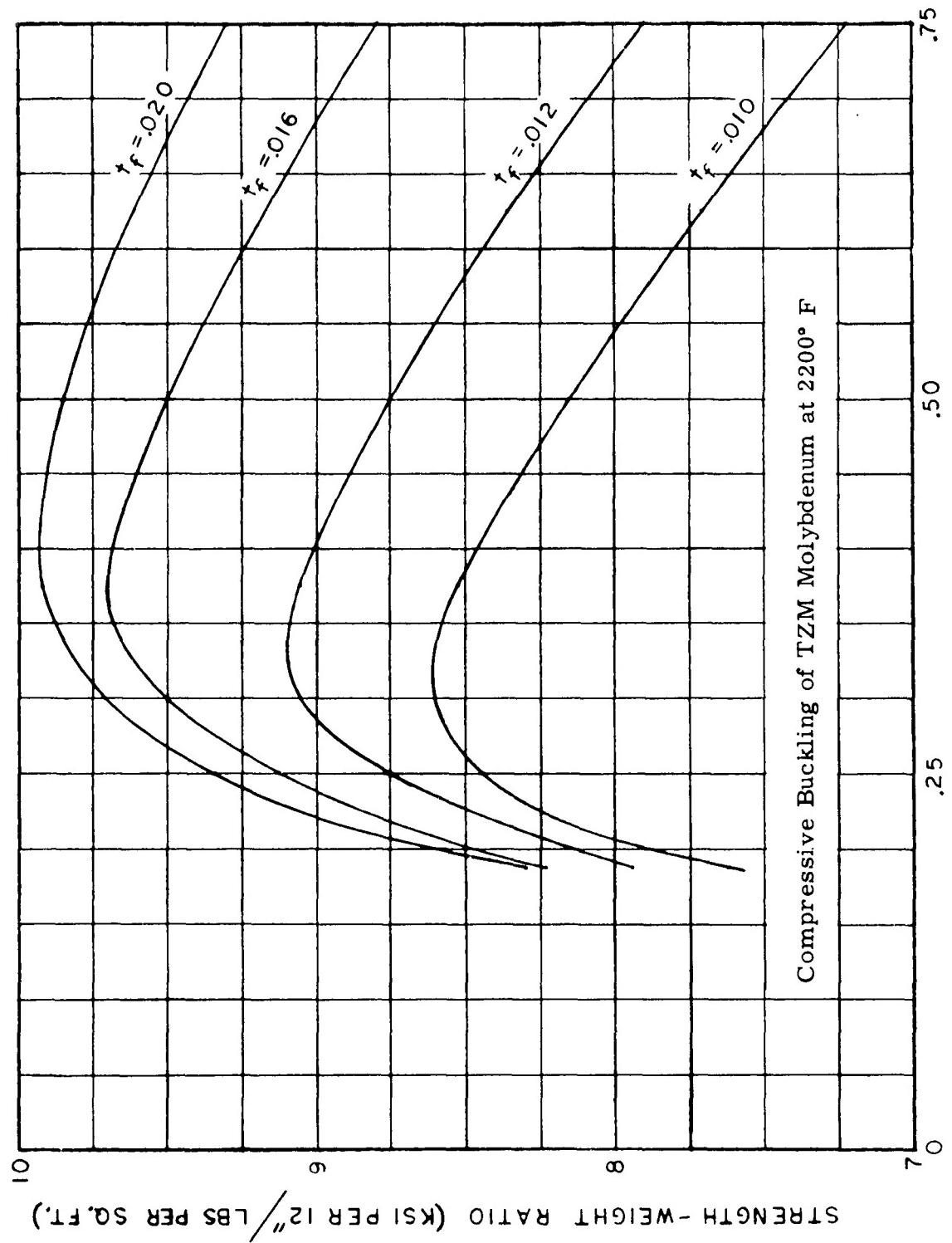


Fig. 18. Test Panel--Strength-Weight Versus Core and Facing Thickness

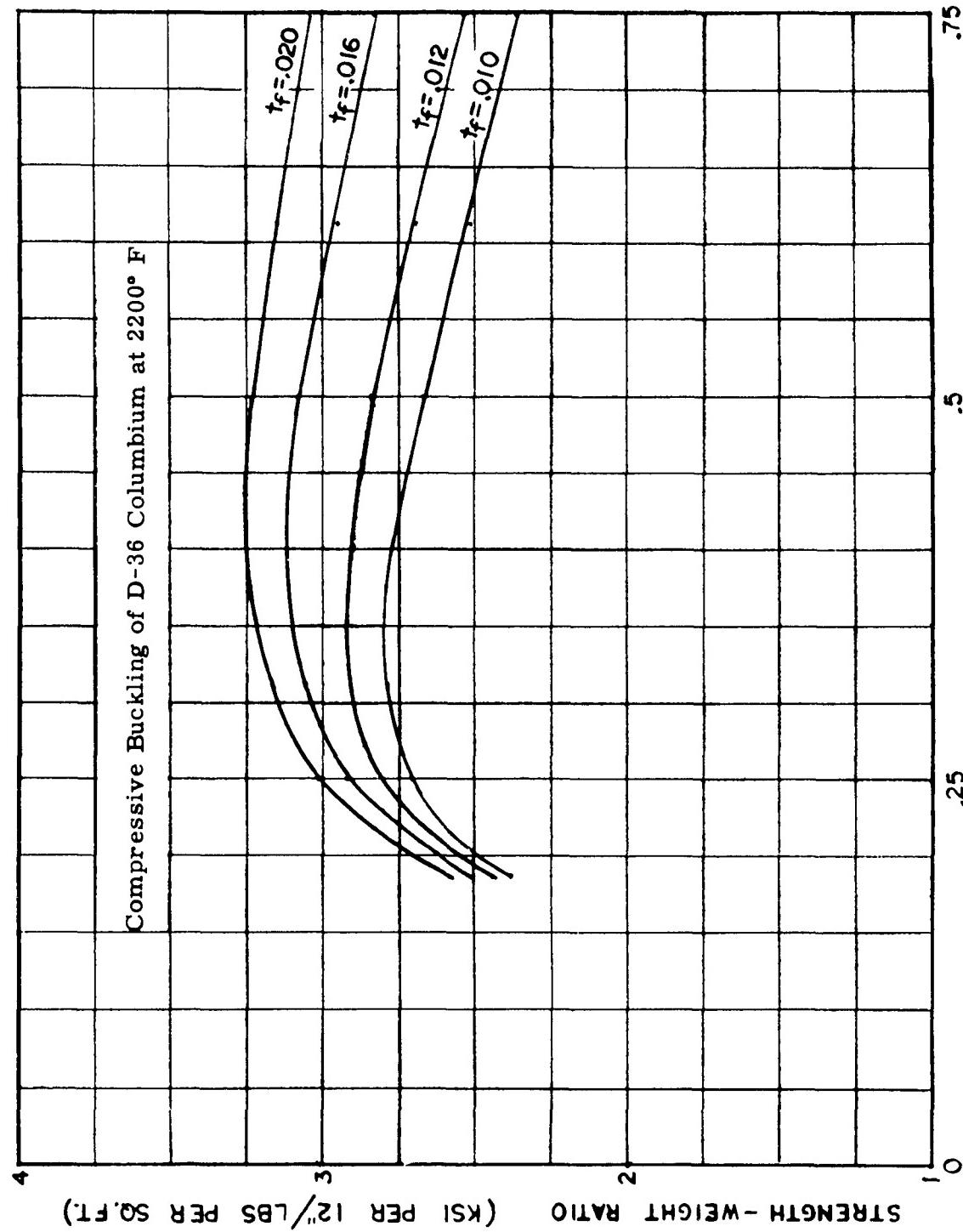


Fig. 19. Test Panel--Strength-Weight Versus Core and Facing Thickness

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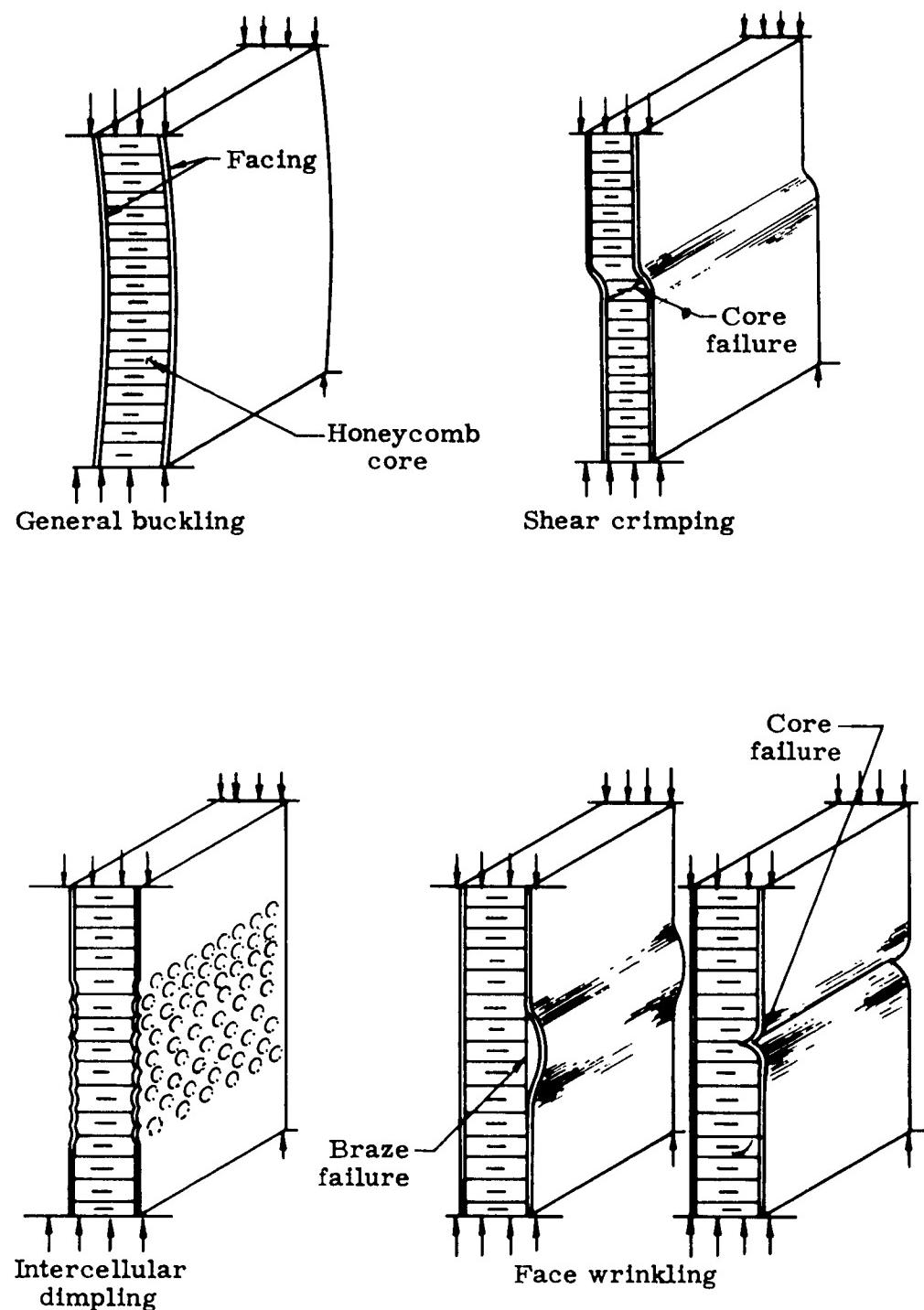


Fig. 20. Types of Failure

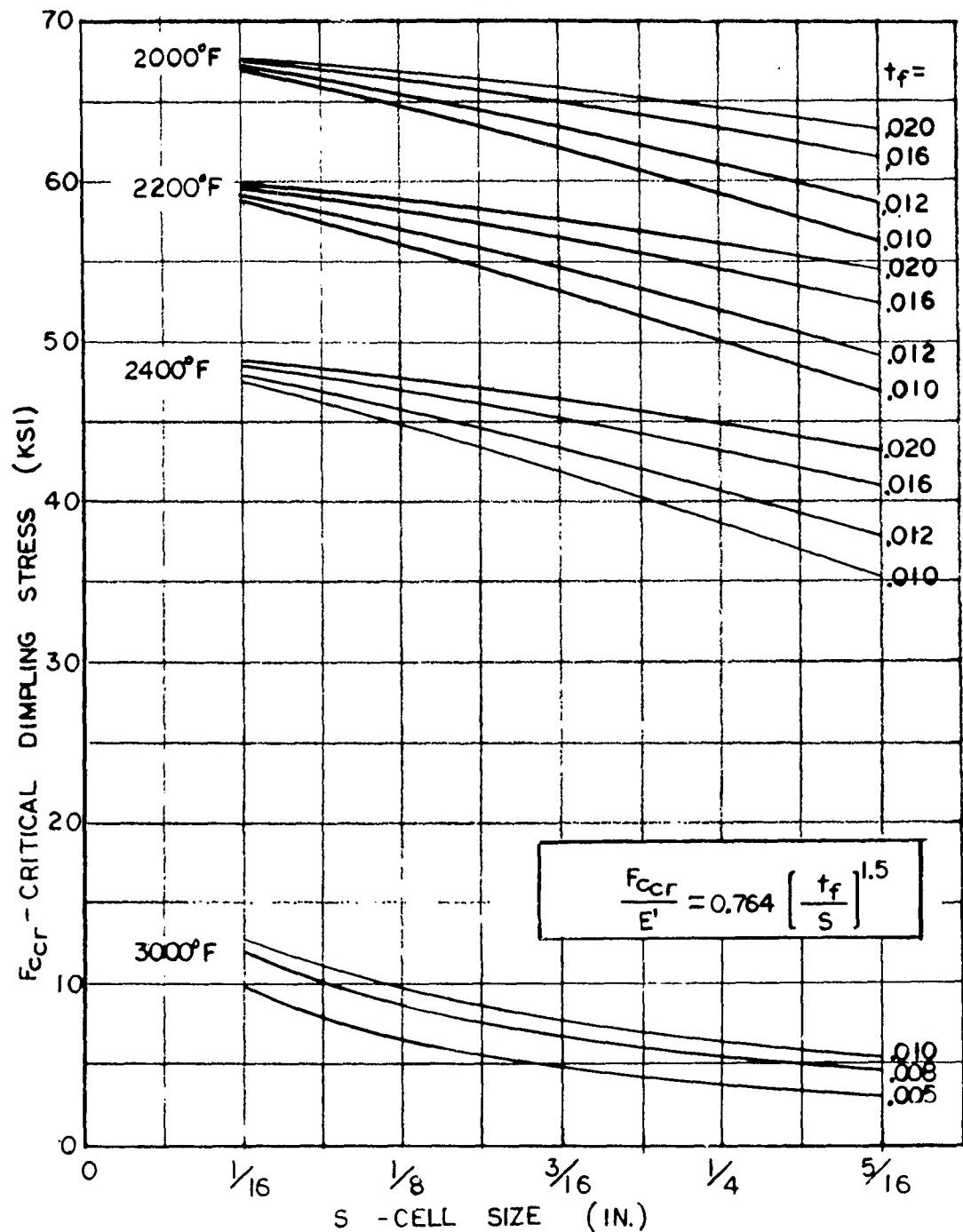


Fig. 21. Test Panel Critical Facing Dimpling Stress--TZM
Molybdenum

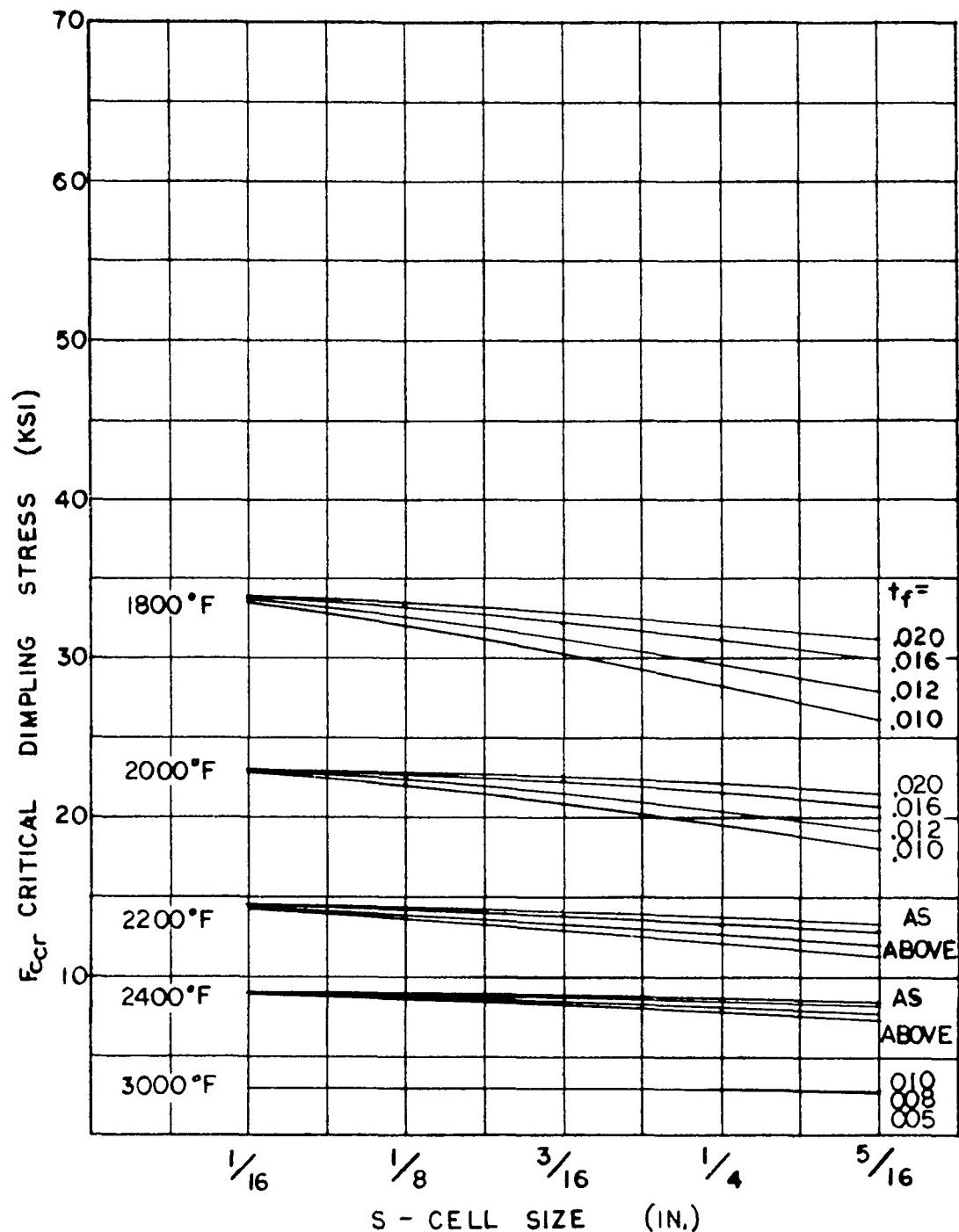


Fig. 22. Test Panel Critical Facing Dimpling Stress--D-36 Columbium

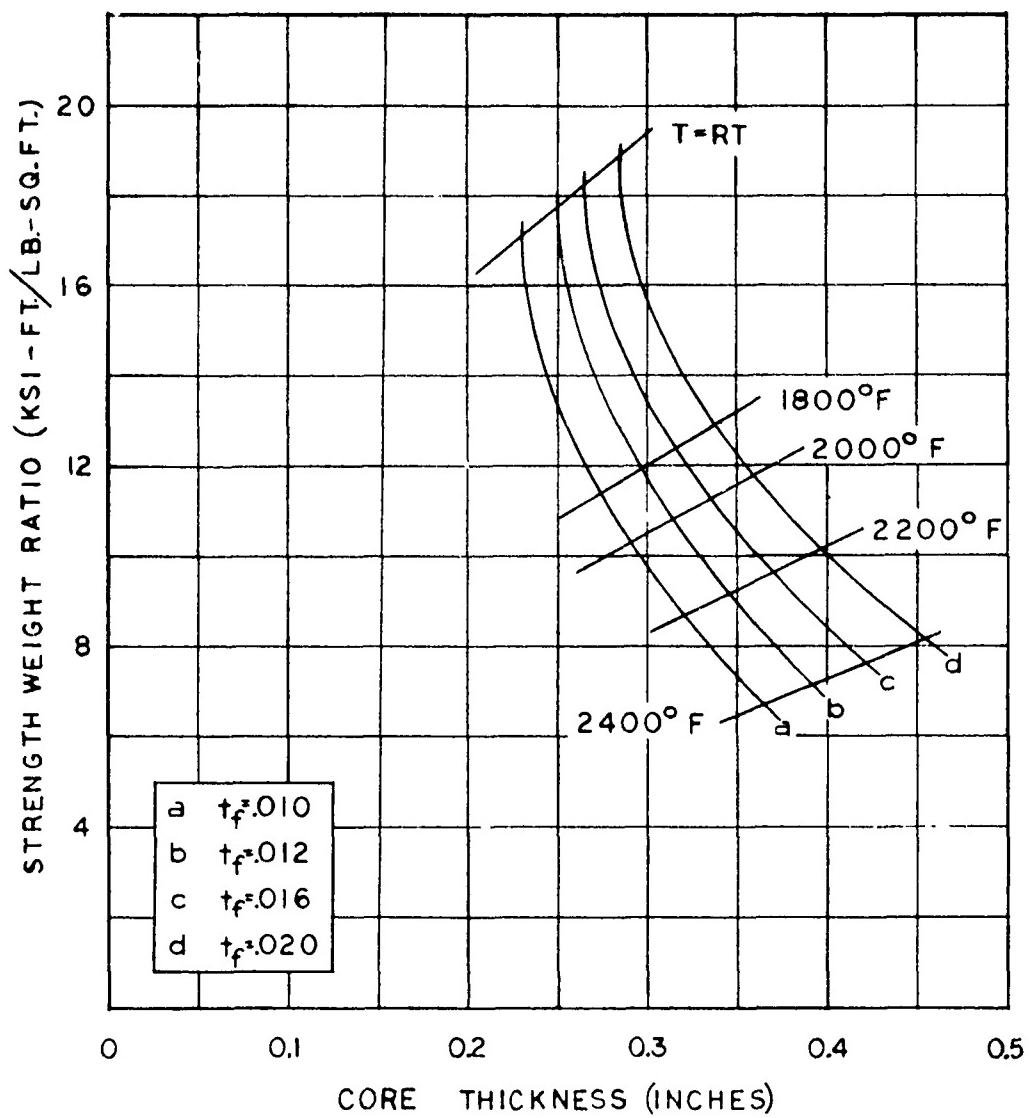


Fig. 23. Strength-Weight Versus Optimum Core Thickness--TZM
Molybdenum Test Panels

(Optimum Core Thickness for Compression Test Panels at Various Temperatures and Facing Thicknesses)

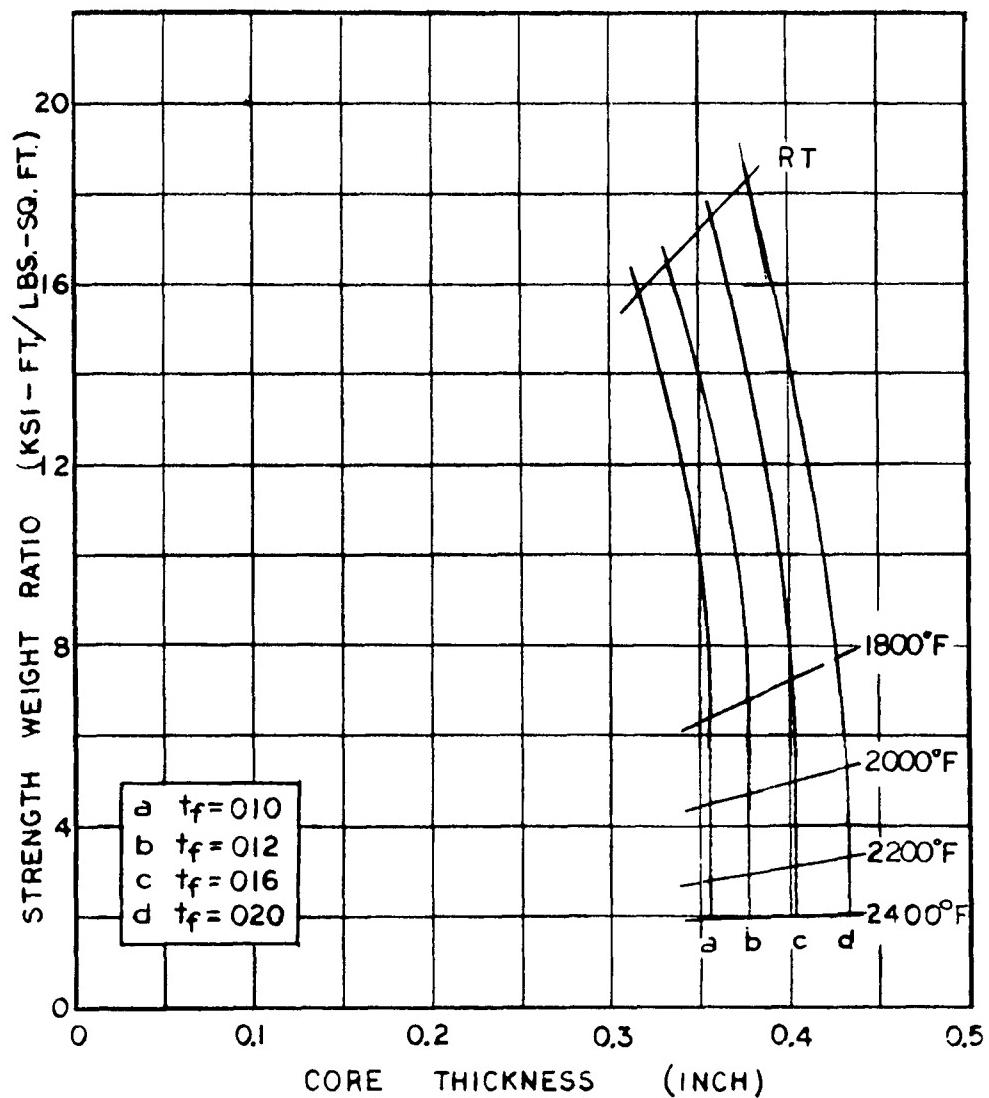


Fig. 24. Strength-Weight Versus Optimum Core Thickness--D-36
Columbium Test Panels

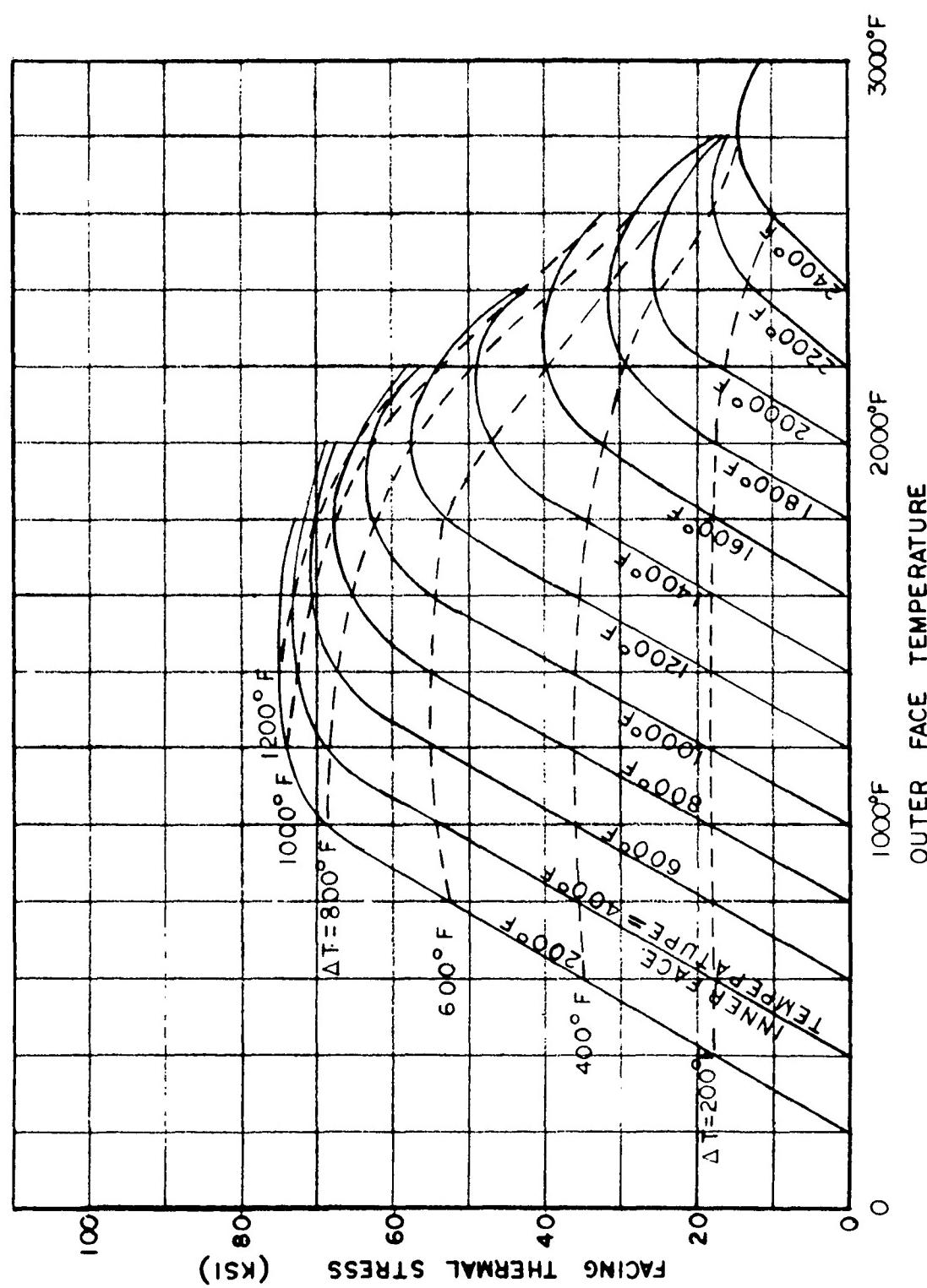


Fig. 25. Thermal Stress--TZM Molybdenum Honeycomb Sandwich Panels

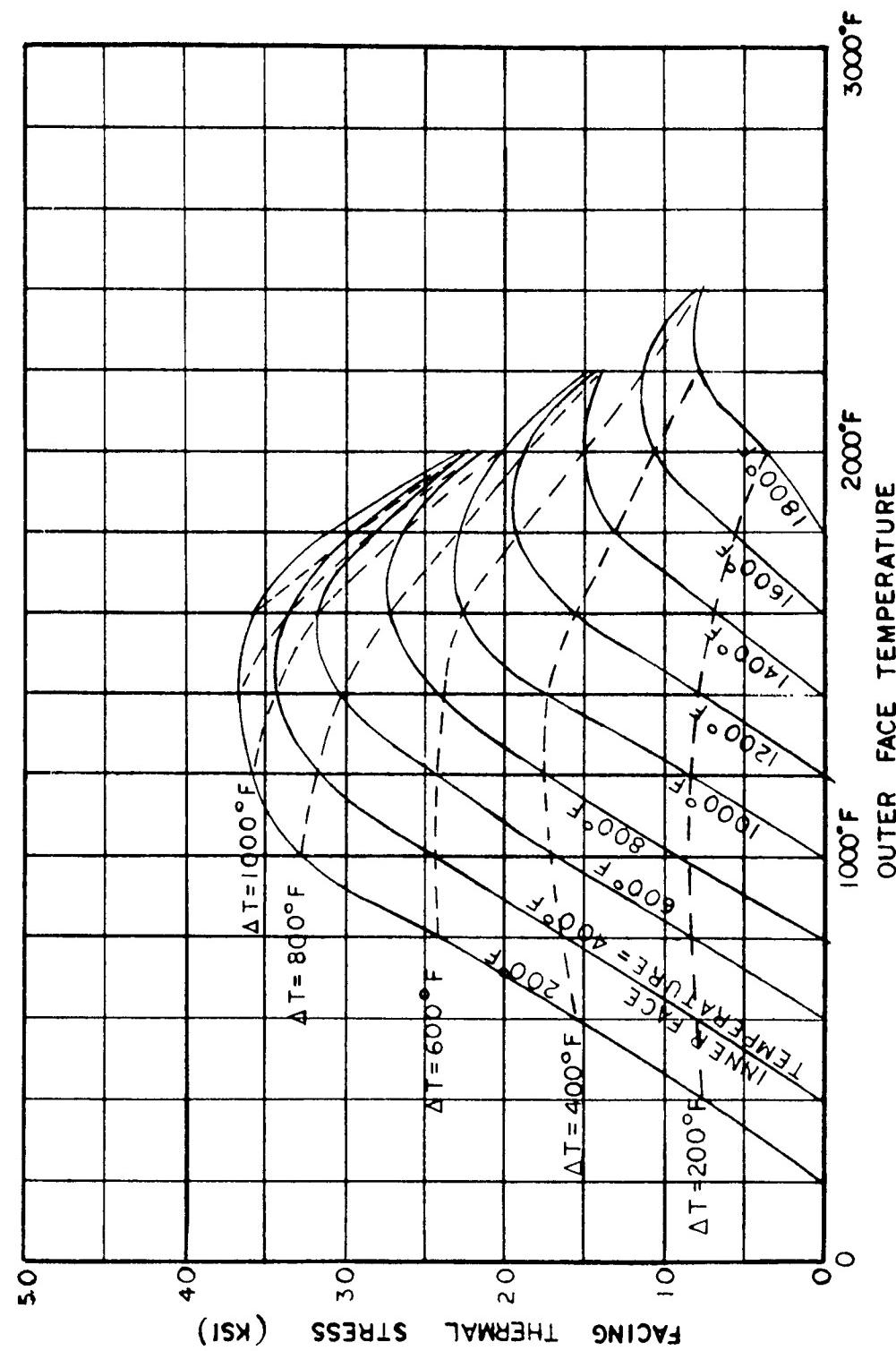


Fig. 26. Thermal Stress--D-36 Columbium Honeycomb Sandwich Panels

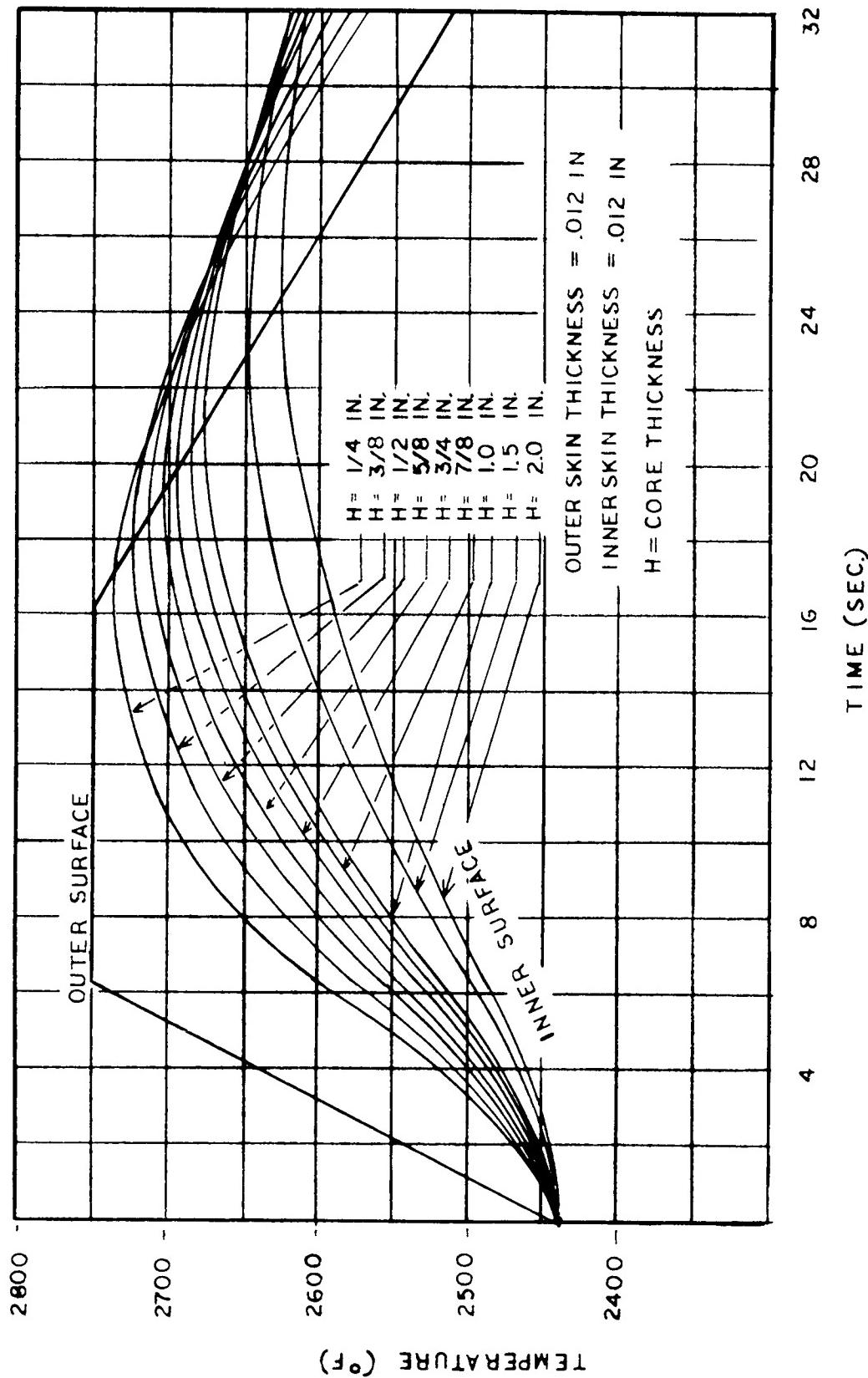


Fig. 27. Outer and Inner Surface Temperature of Molybdenum Honeycomb During a Thermal Shock

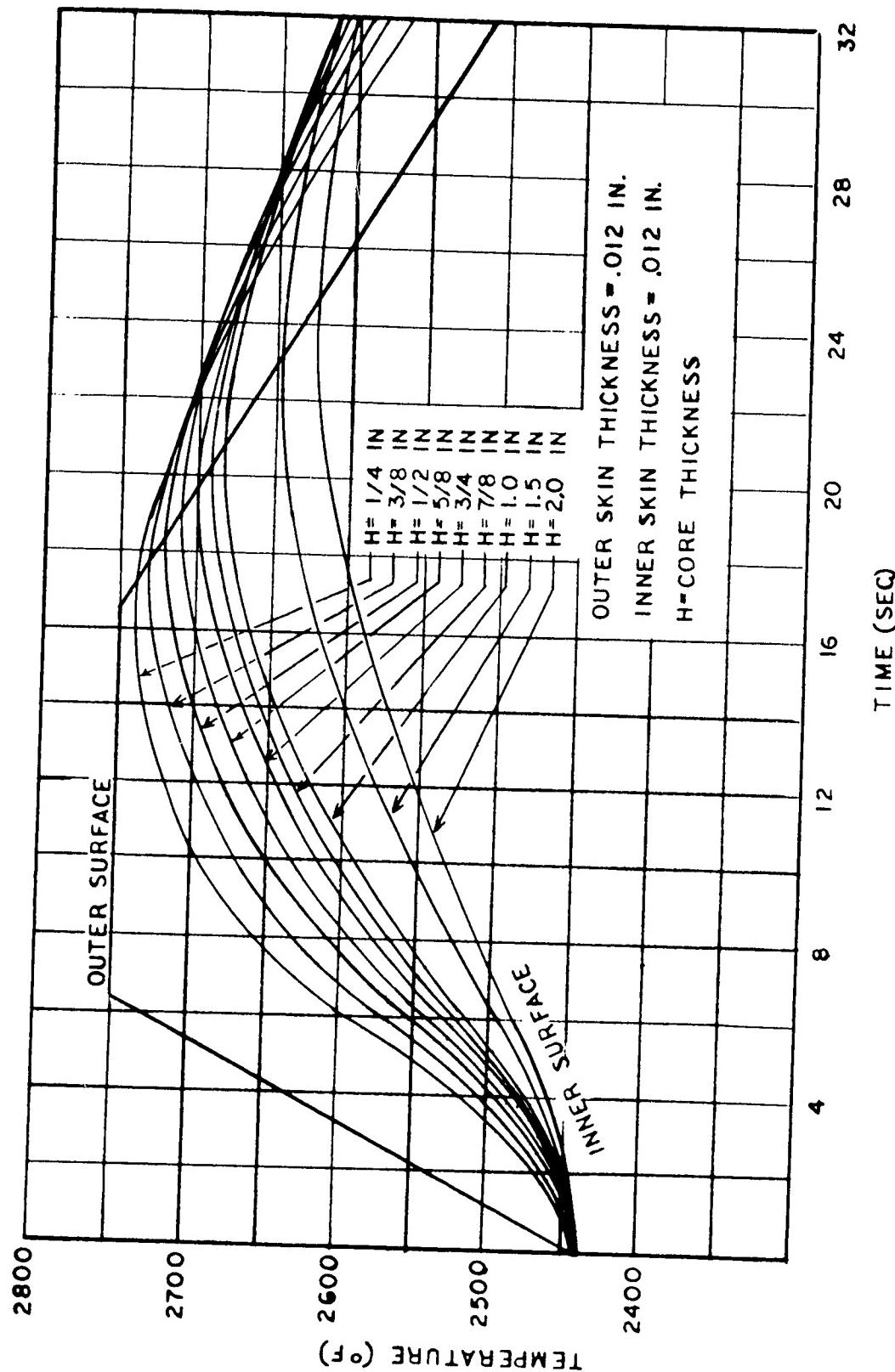


Fig. 28. Outer and Inner Surface Temperature of Columbium Honeycomb During a Thermal Shock

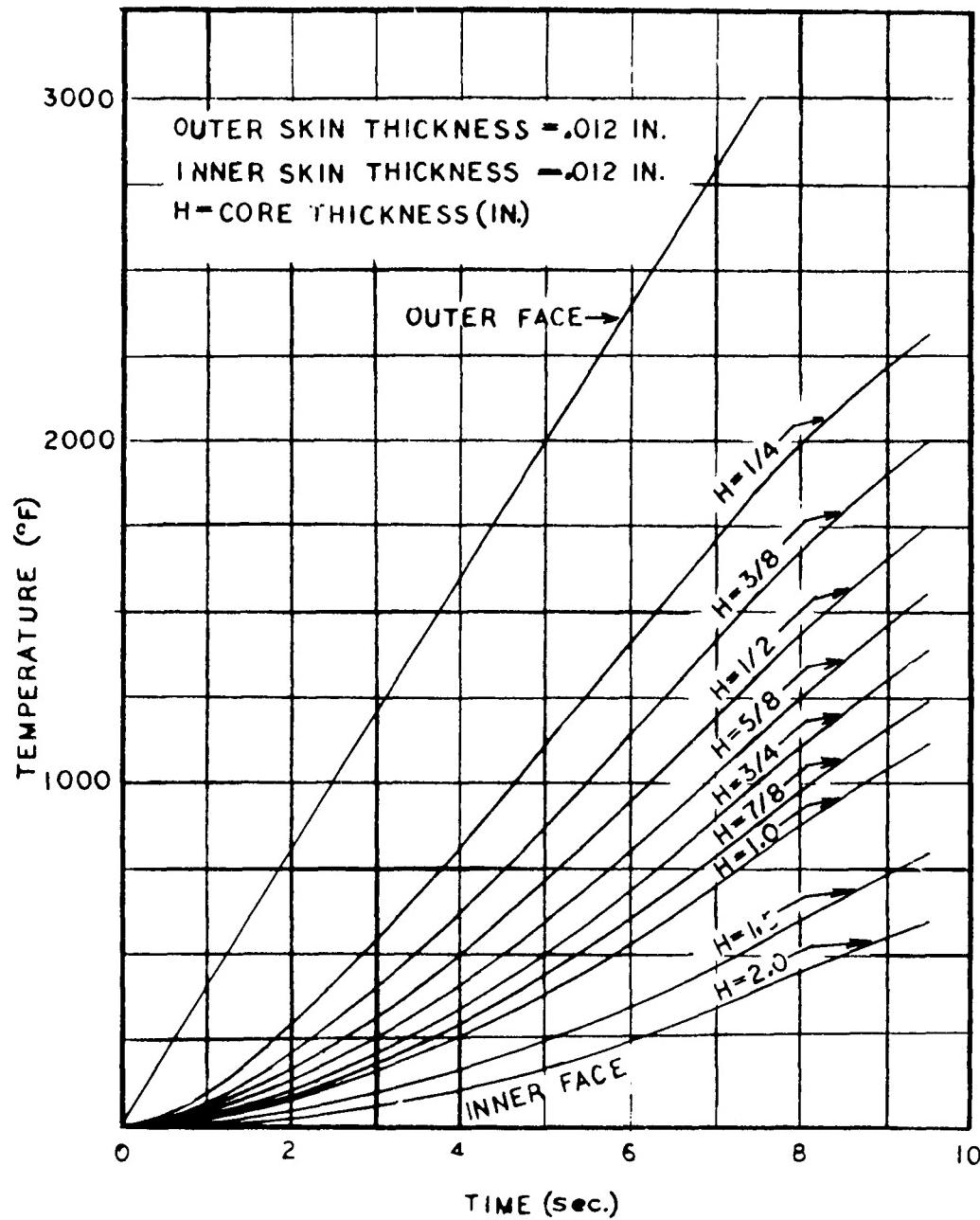


Fig. 29. Outer and Inner Surface Temperature of Molybdenum Honeycomb During a Thermal Shock

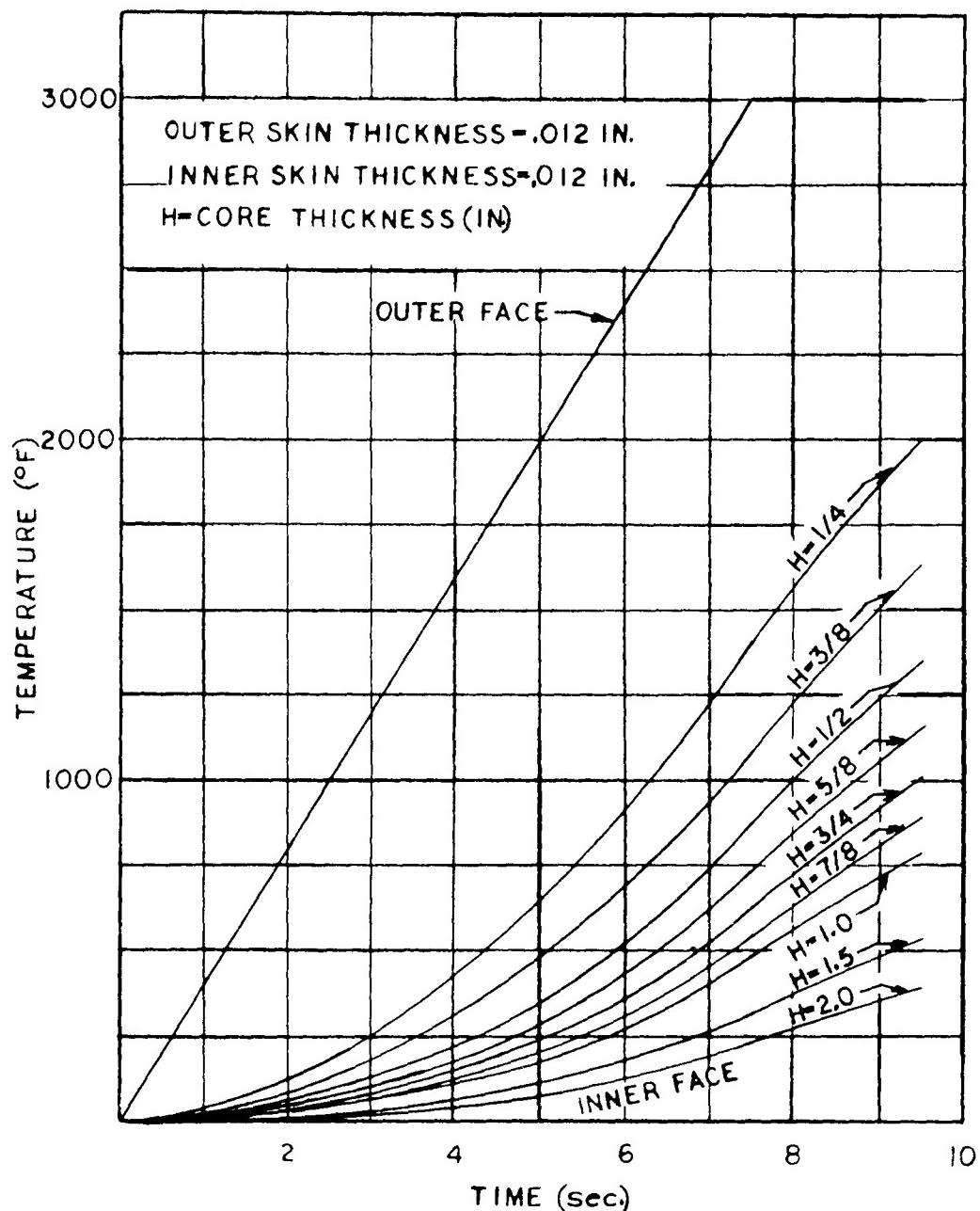


Fig. 30. Outer and Inner Surface Temperature of Columbium Honeycomb During a Thermal Shock

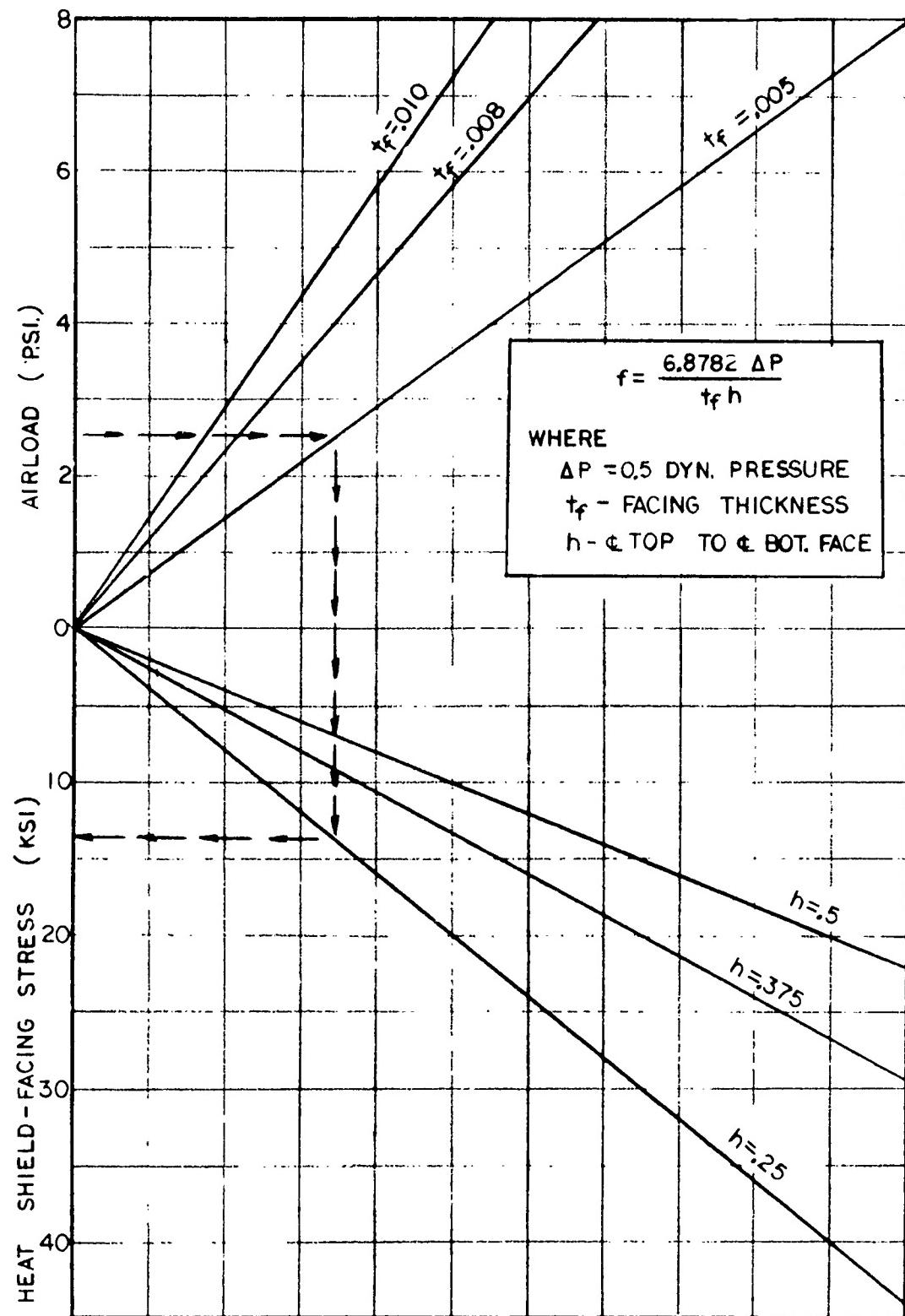


Fig. 31. Heat Shield Panel--Facing Stress at Various Air Loads and Panel Variables

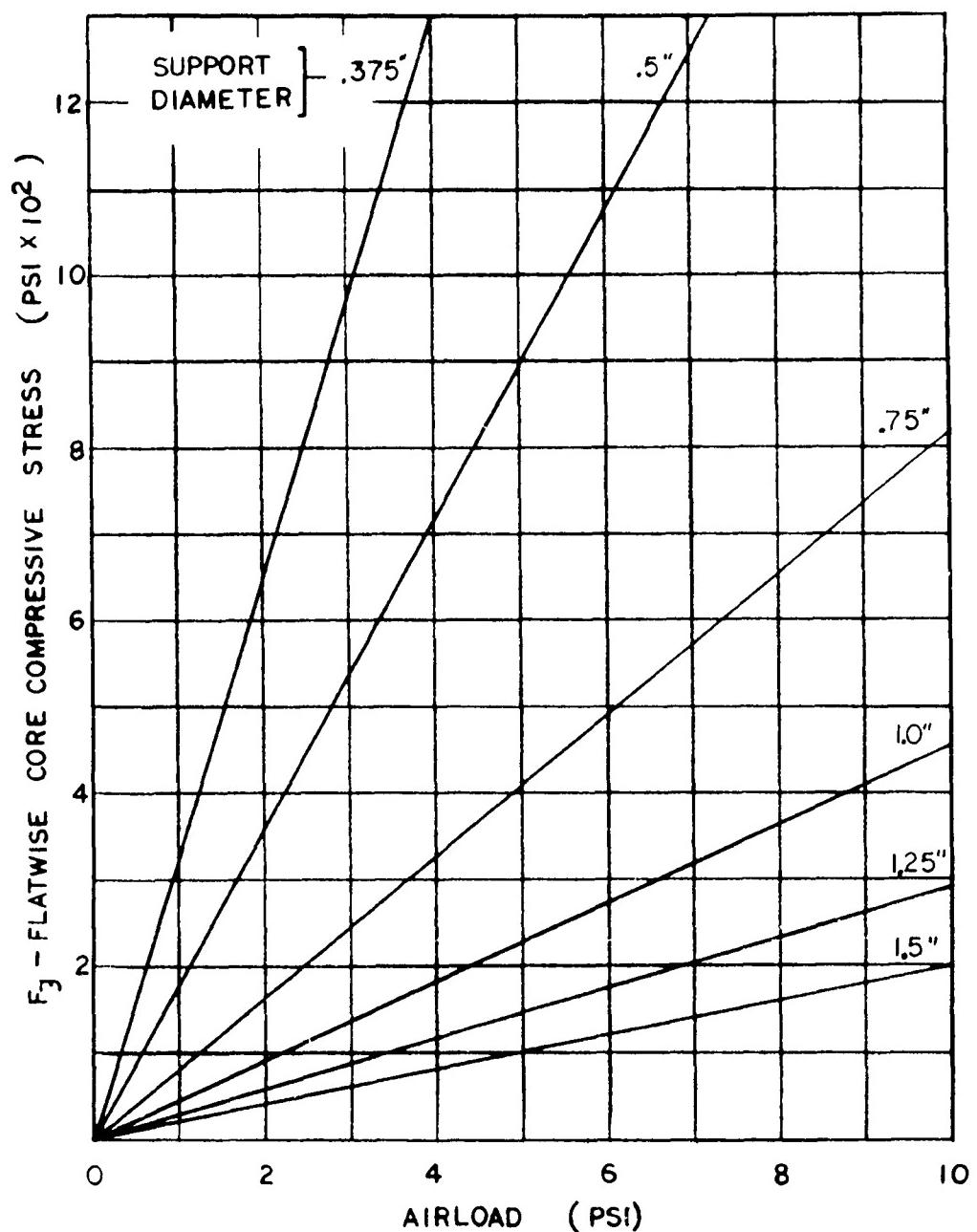


Fig. 32. Heat Shield Panel--Core Compressive Stress at Various Air Loads and Support Diameters

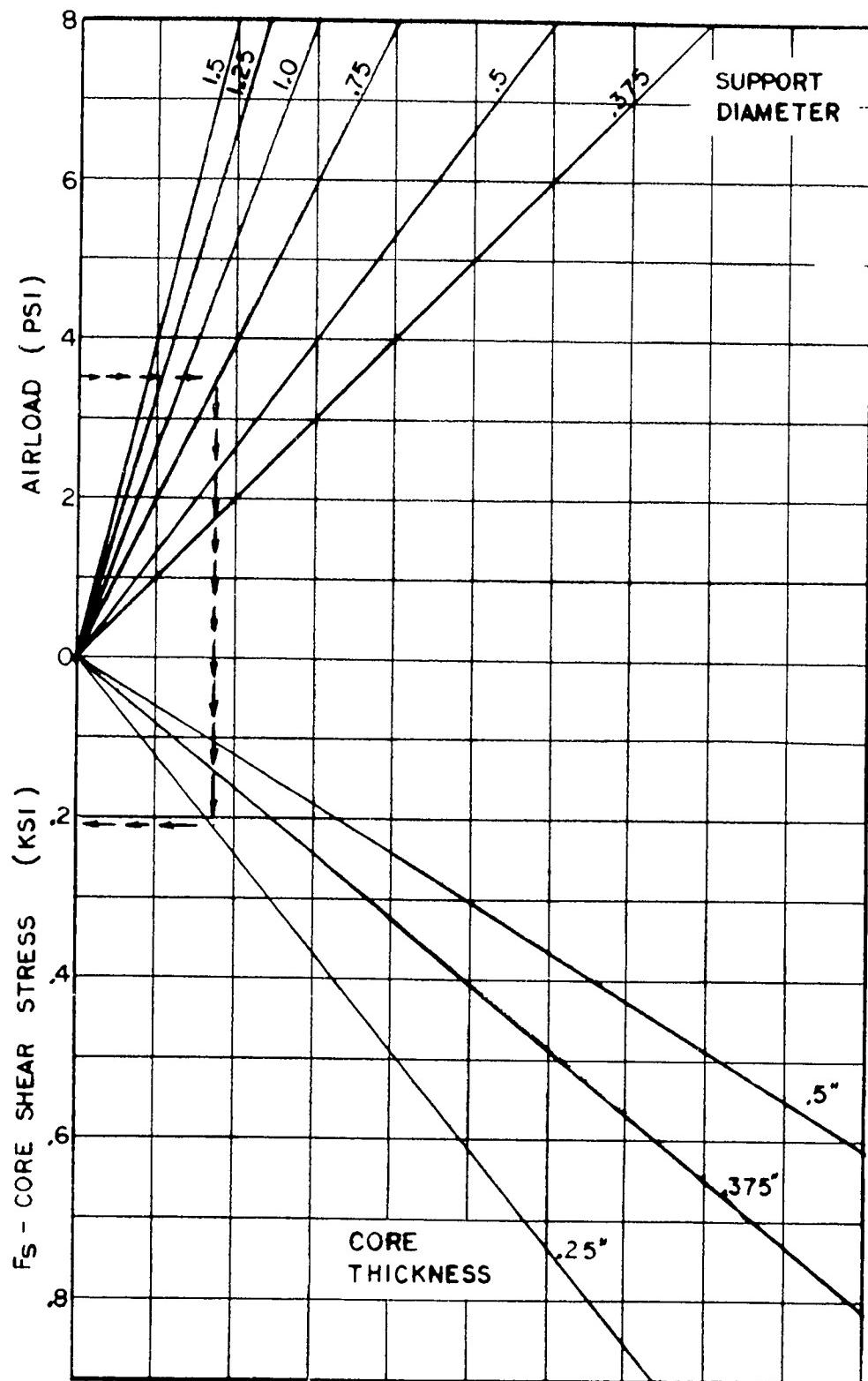


Fig. 33. Heat Shield Panel--Core Shear Stress at Various Air Loads,
Support Diameters and Panel Thicknesses



Fig. 34. Seven-Inch Hot Gas Facility--4-Inch Diameter Al-Sn Coated Molybdenum Specimen in Test



Fig. 35. Four-Inch Diameter Al-Sn Coated Molybdenum Specimen After Testing

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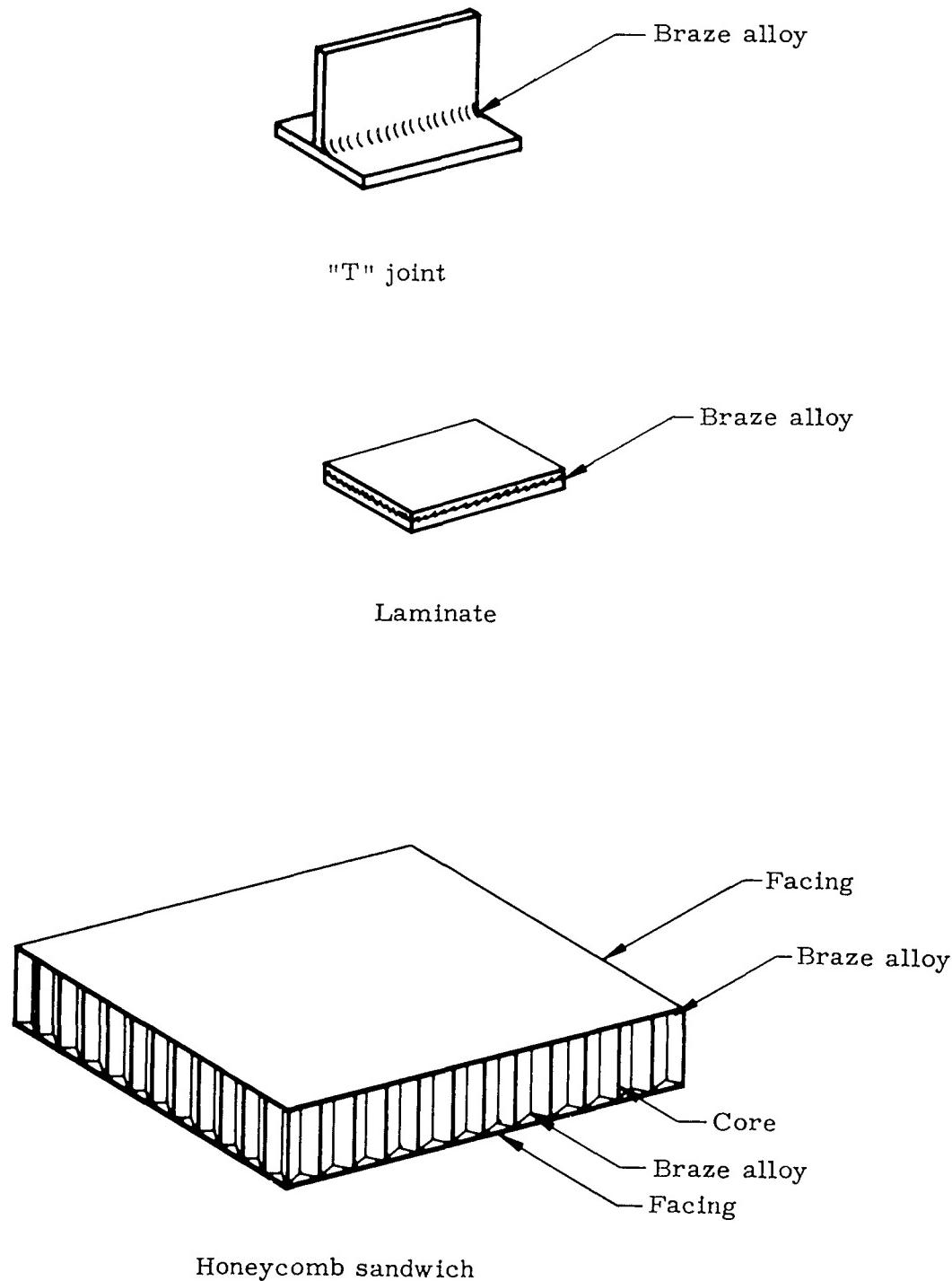


Fig. 36. Specimen Configurations for Braze Alloy Evaluation and Selection

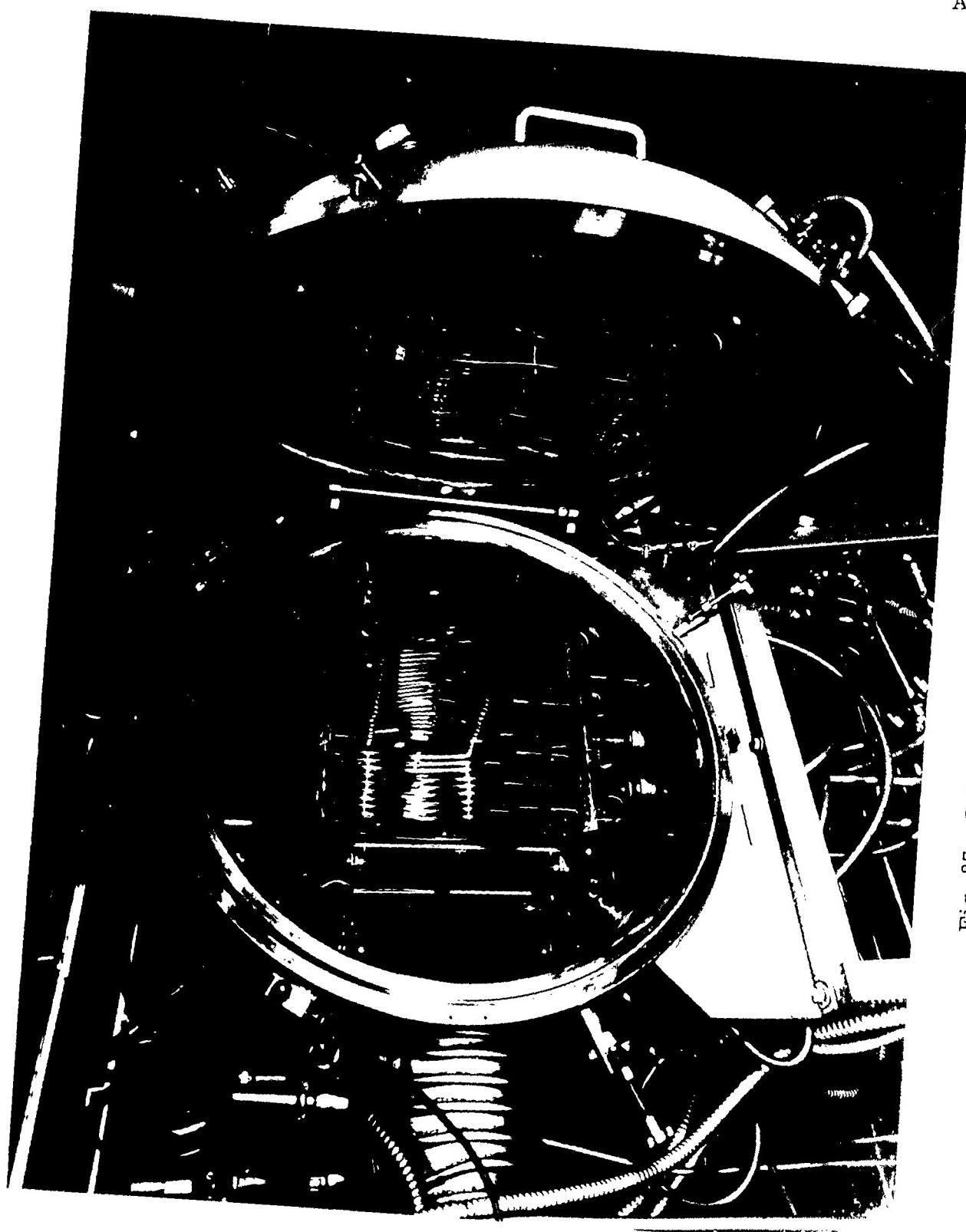


Fig. 37. Cold-Wall Vacuum Brazing Furnace

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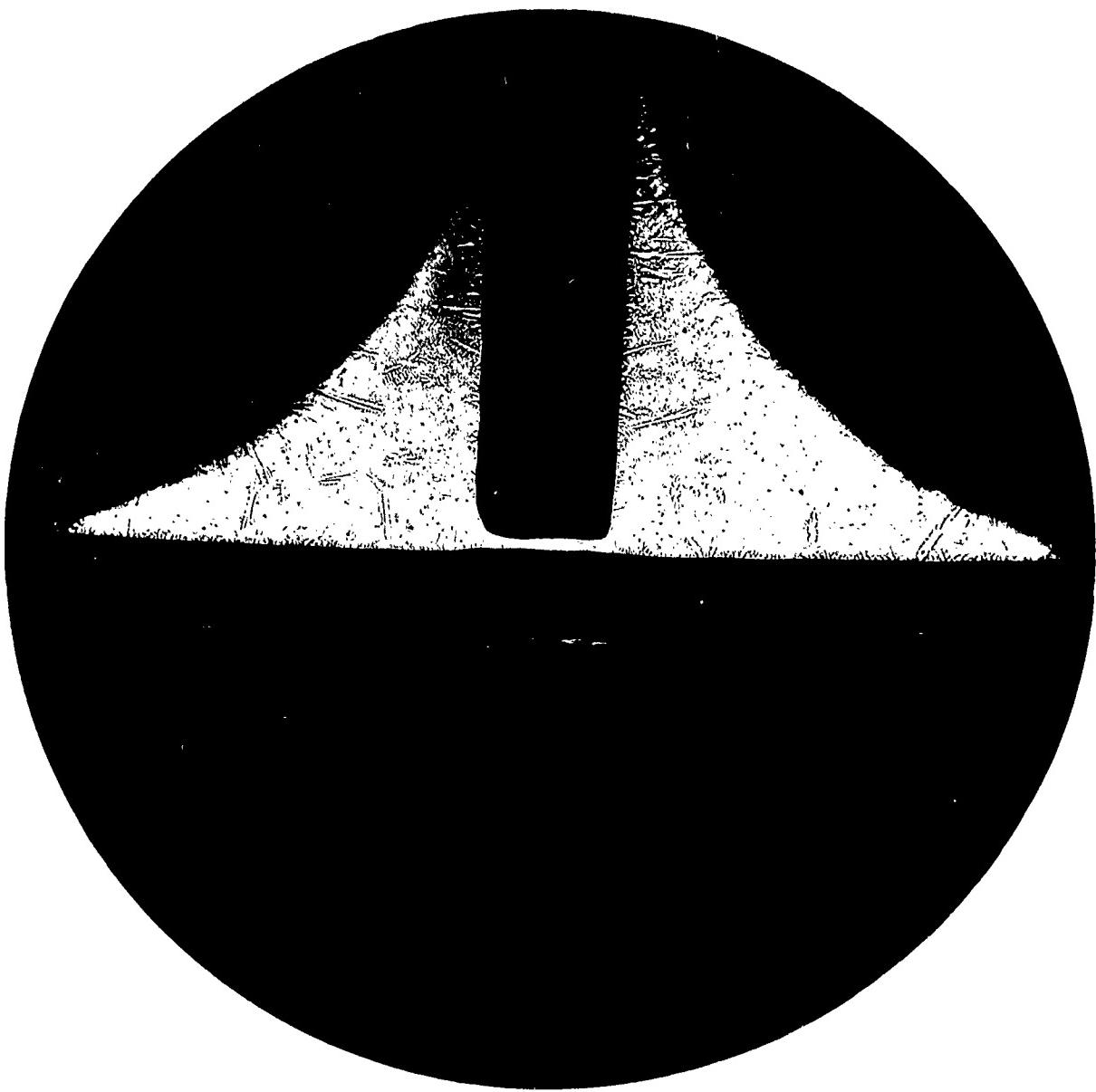


Photomicrograph showing that recrystallization of TZM 0.002 foil occurs within 5 minutes at 2600° F with attending grain growth for longer time periods. (400x)

Specimens

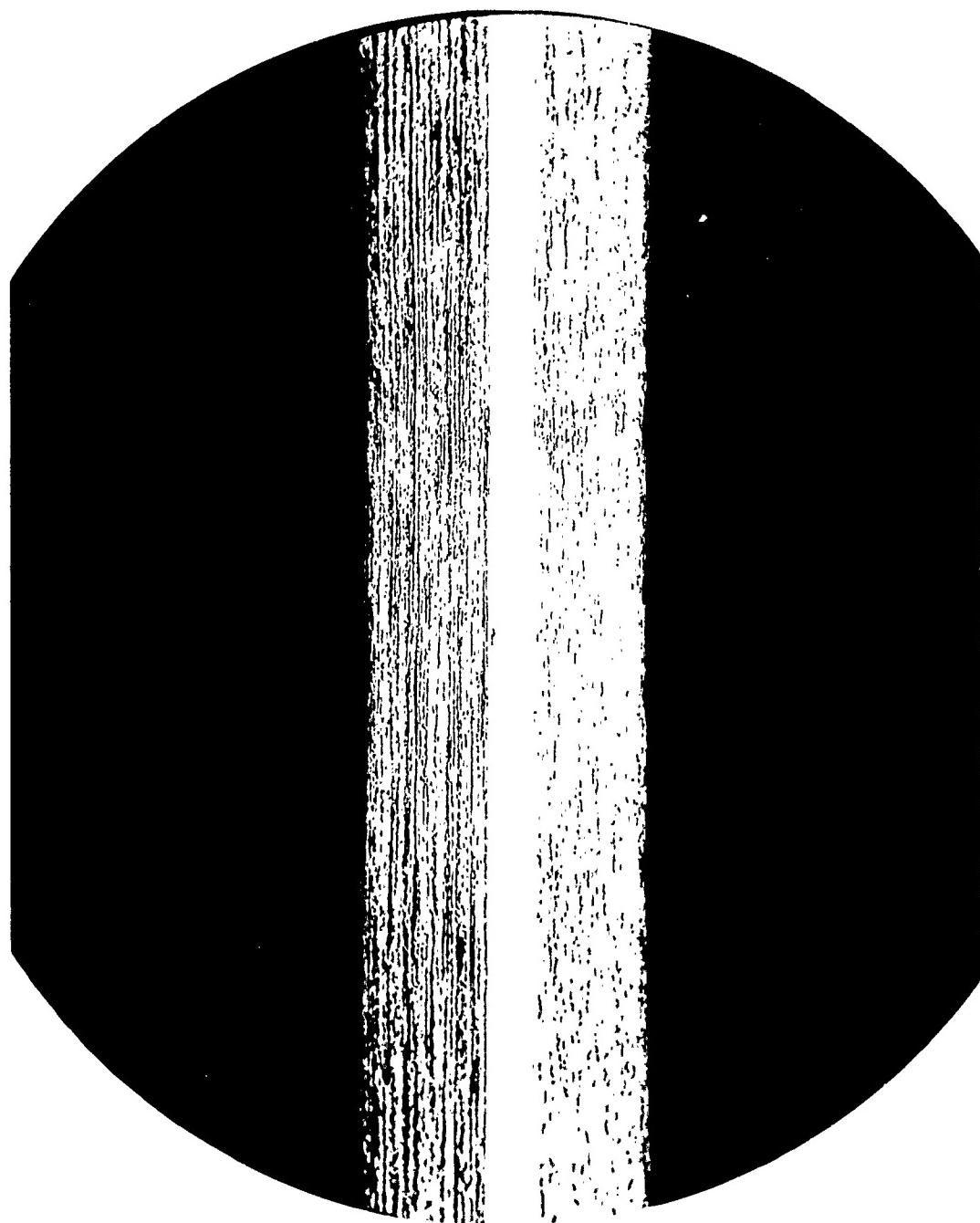
M10	TZM--as received
M11	2600°--5 min
M12	2600°--15 min
M13	2600°--30 min

Fig. 38. TZM Foil Recrystallization



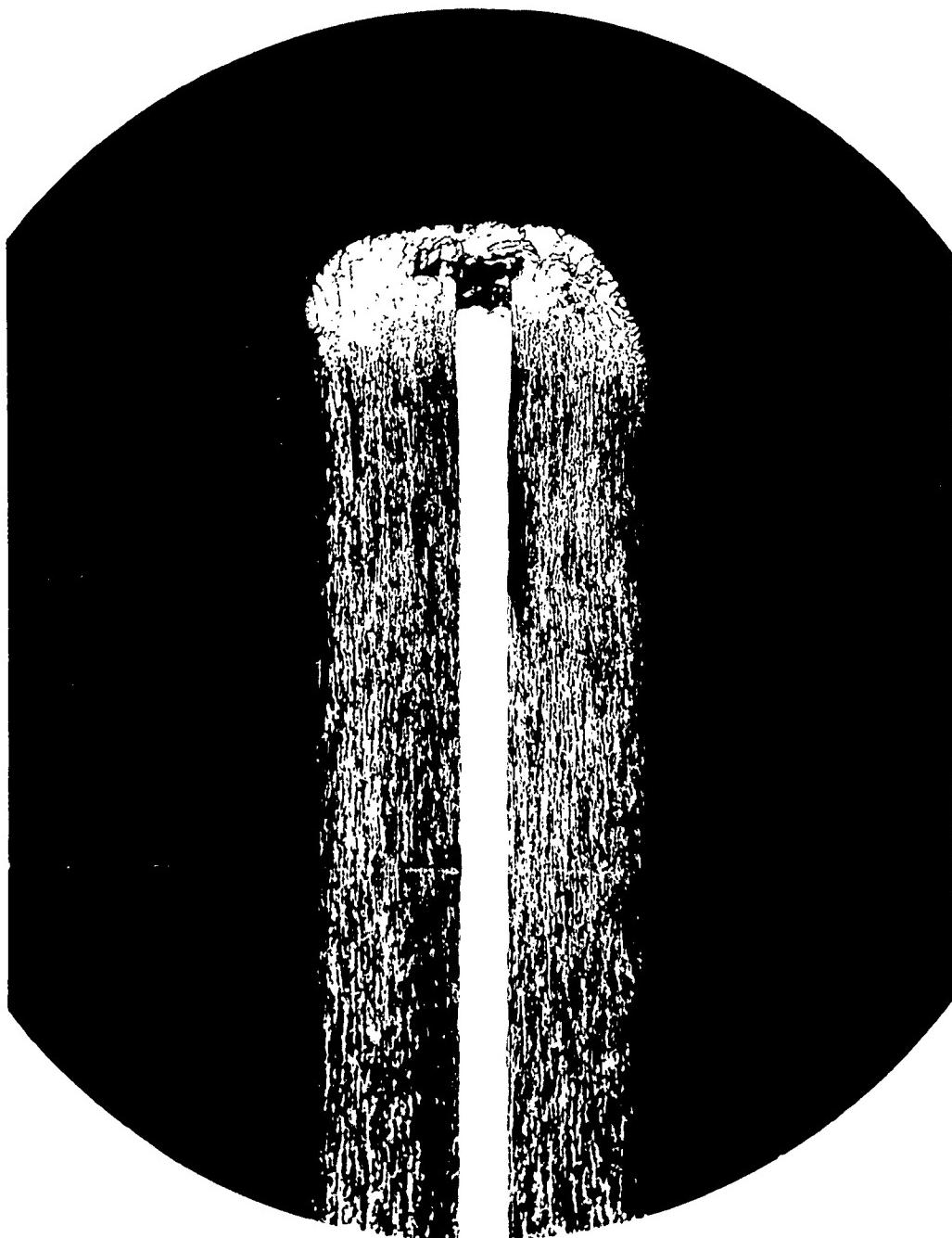
TZM T-joint brazed with
Haynes 2⁵ alloy at 2600° F.
Some alloying has occurred
with negligible erosion of
base material. (75x)

Fig. 39. TZM Brazed T-Joint



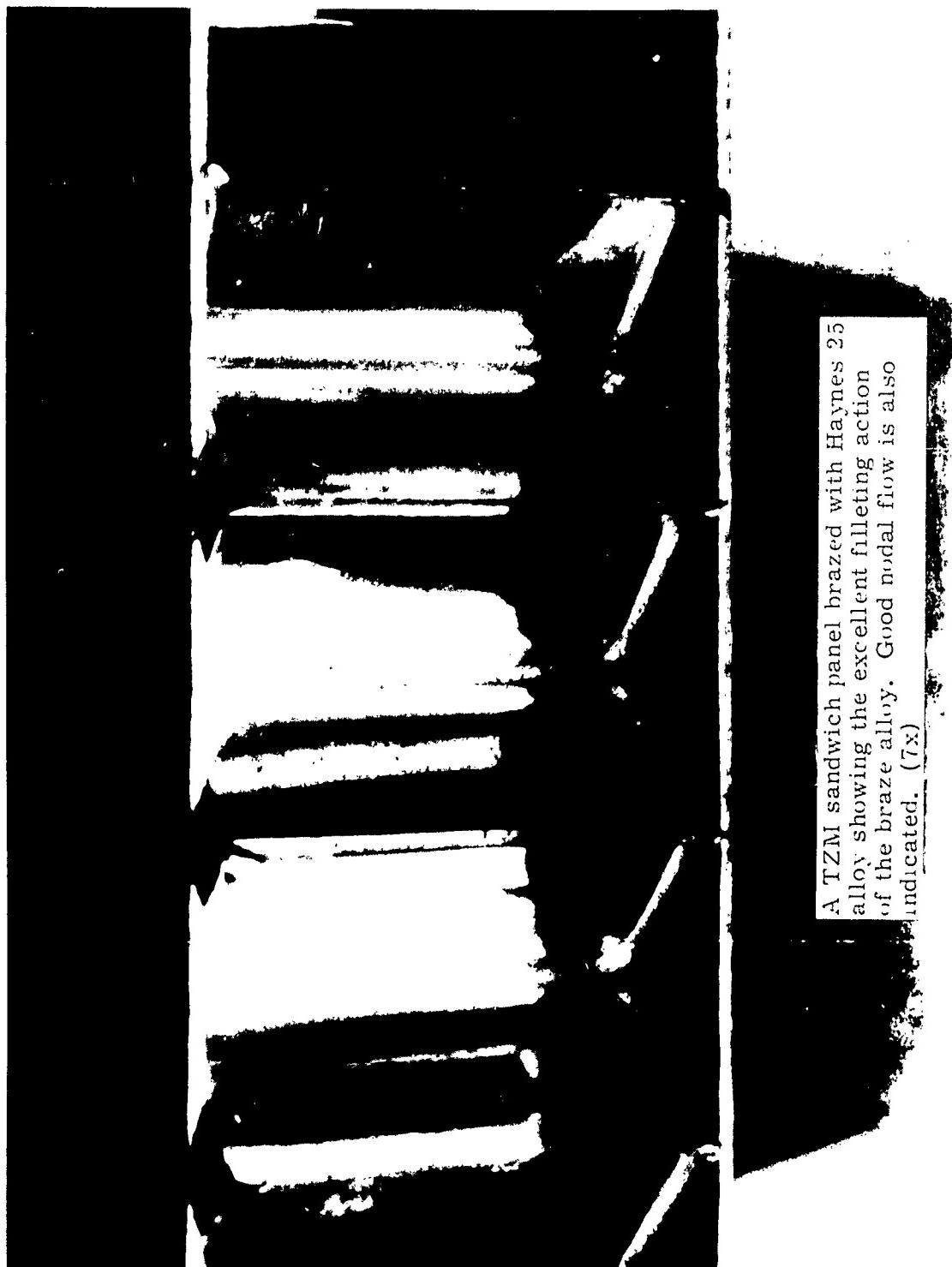
TZM laminate brazed with Haynes 25
alloy at 2600° F. The lack of void
areas indicates the excellent wettability
of the braze alloy. (75X)

Fig. 40. TZM Brazed Laminate



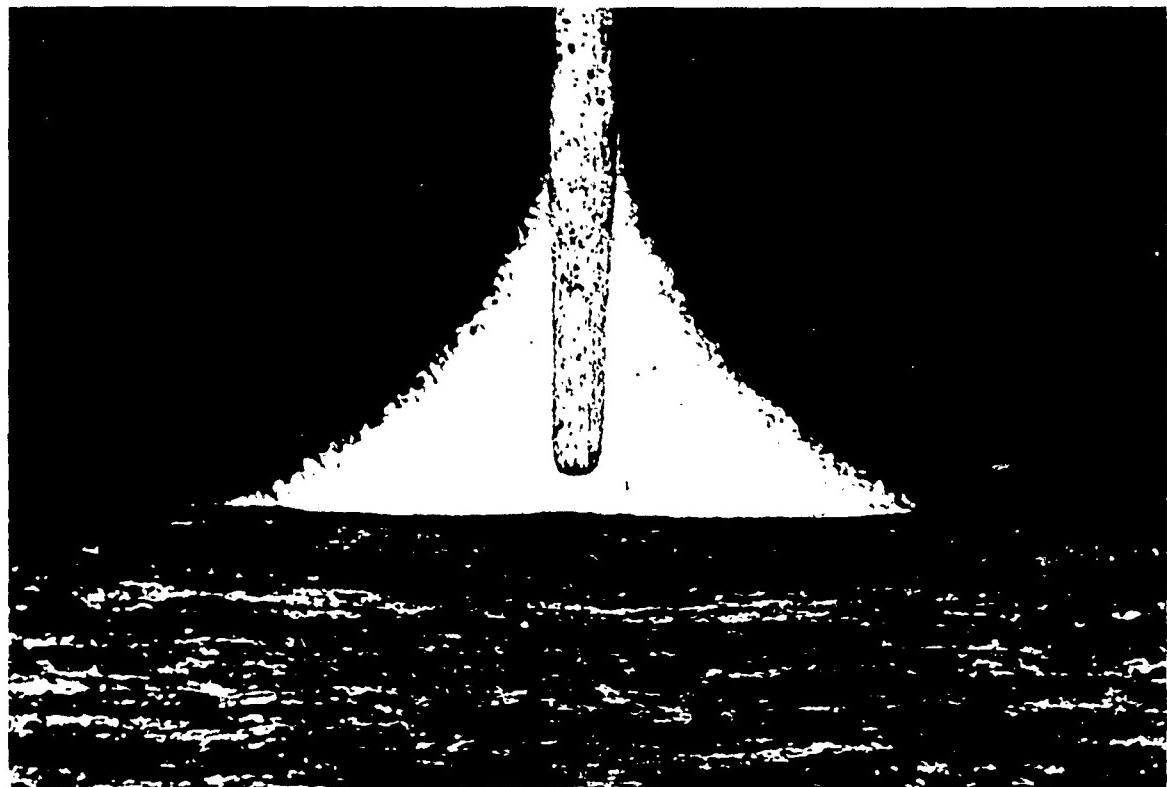
A photomicrograph of a TZM laminate brazed with Haynes 25 alloy and subsequently electron beam welded on an edge. The braze alloy had no effect on the welded joint. (75x)

Fig. 41. TZM Brazed Laminate



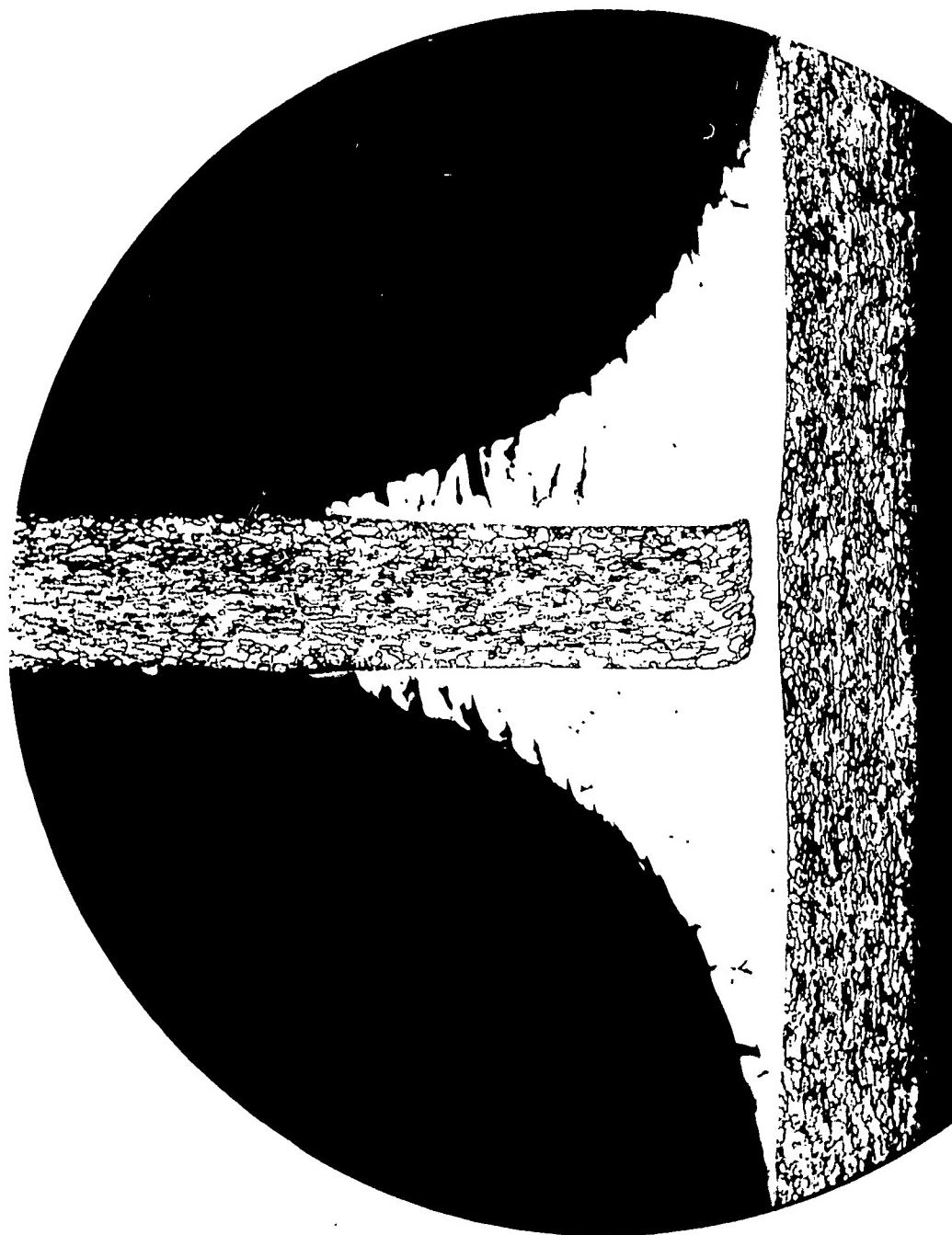
A TZM sandwich panel brazed with Haynes 25 alloy showing the excellent filleting action of the braze alloy. Good nodal flow is also indicated. (7x)

Fig. 42. TZM Brazed Sandwich Panel



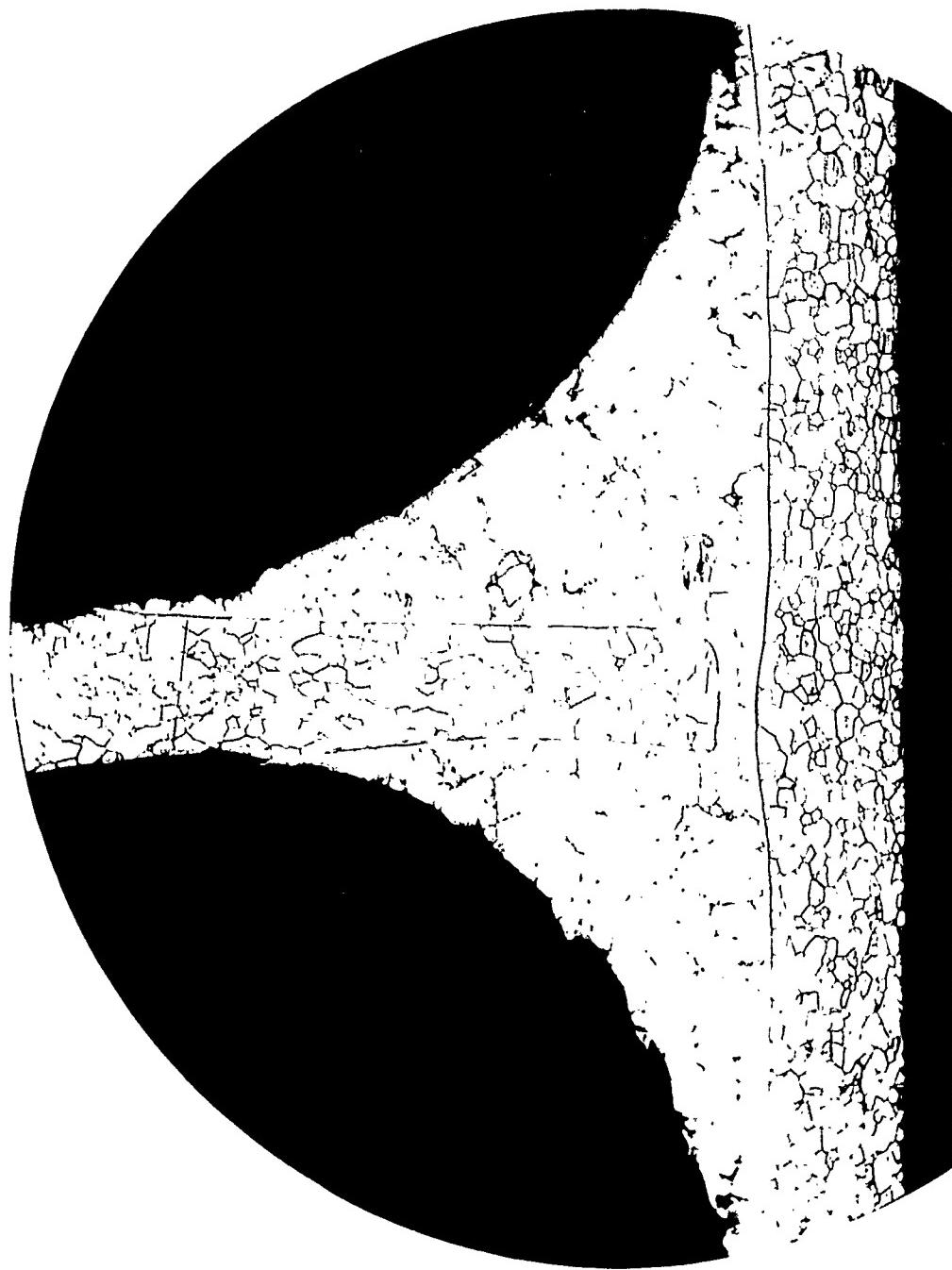
A photomicrograph showing a typical TZM core-to-skin fillet. The panel was brazed at 2600° F with Haynes 25 alloy. (200x)

Fig. 43. Typical TZM Core-to-Skin Fillet



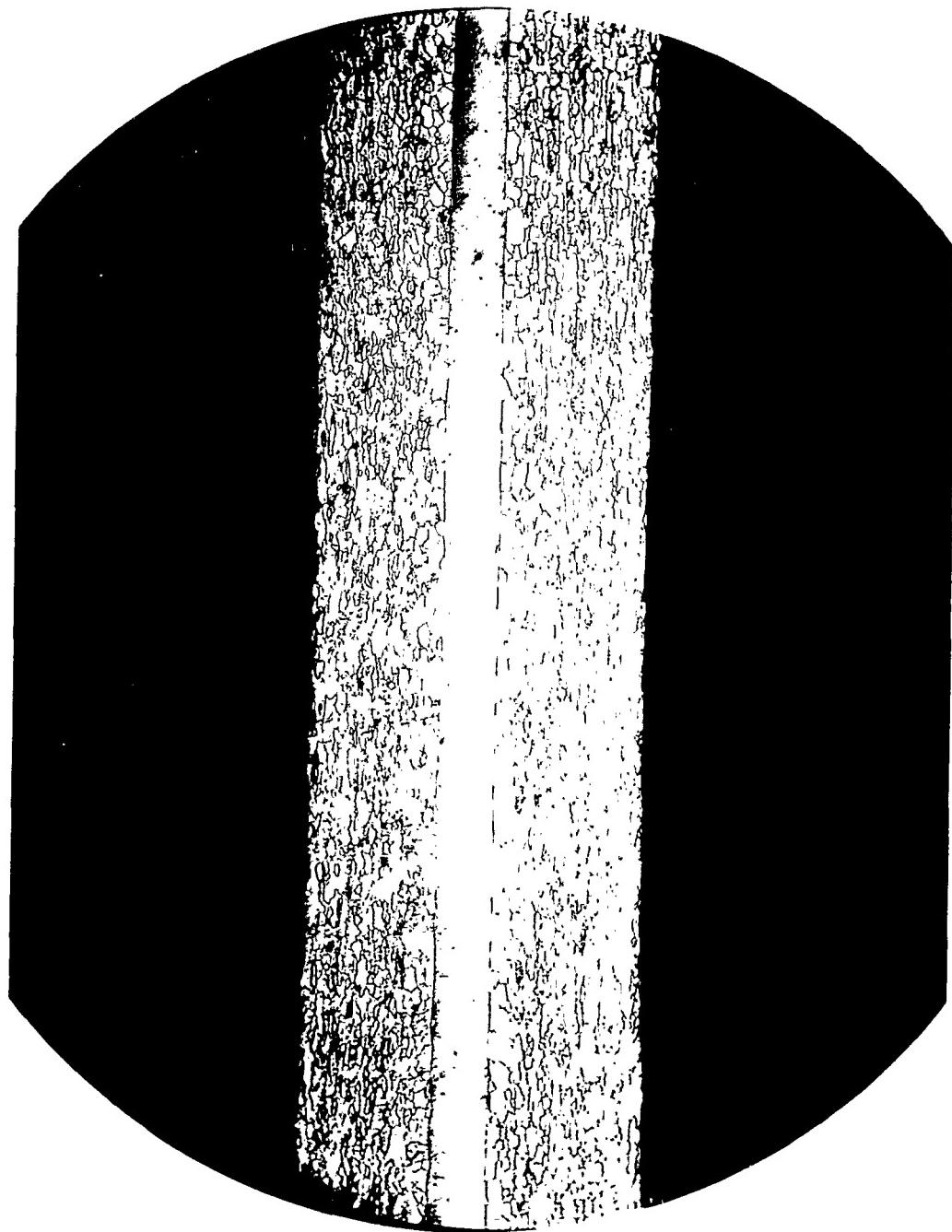
A TZM T-joint brazed with pure palladium at 2900° F. The voids shown in fillet are shrinkage voids. Very little alloying and erosion have occurred. (75x)

Fig. 44. TZM T-Joint--Pure Palladium Braze



A TZM T-joint brazed with commercially pure titanium at 3100° F.
An alloy bond is evident with slight erosion of the parent metal. (75x)

Fig. 45. TZM T-Joint--Pure Titanium Braze



A photomicrograph of a TZM
laminate brazed with commercially
pure titanium at 3100° F. (75x)

Fig. 46. TZM Laminate--Pure Titanium Braze



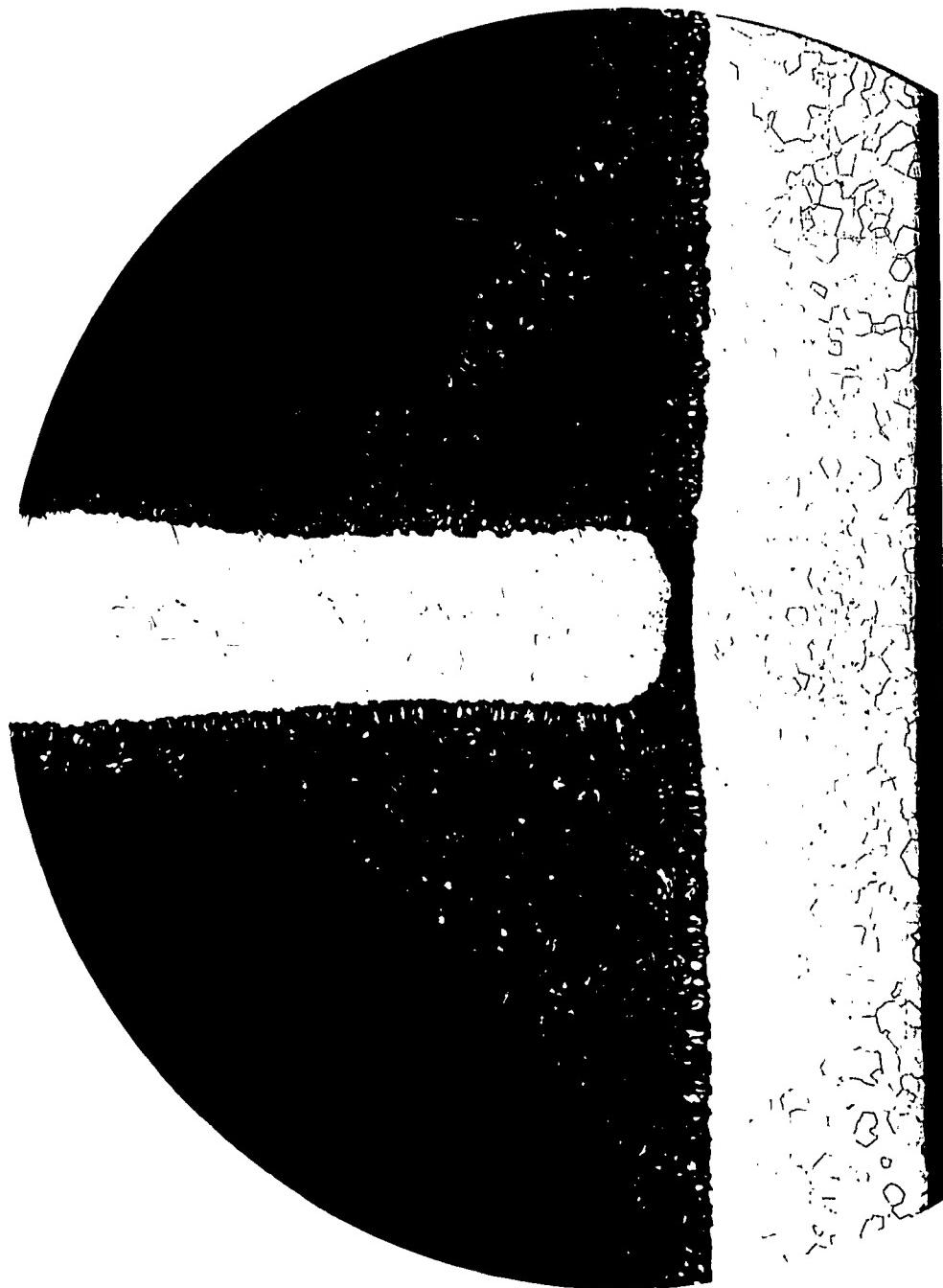
A TZM sandwich panel brazed with
commercially pure titanium at 3100° F.
Good filleting and nodal flow is indicated.
However, the core material is extremely
brittle.

Fig. 47. TZM Sandwich Panel--Pure Titanium Braze



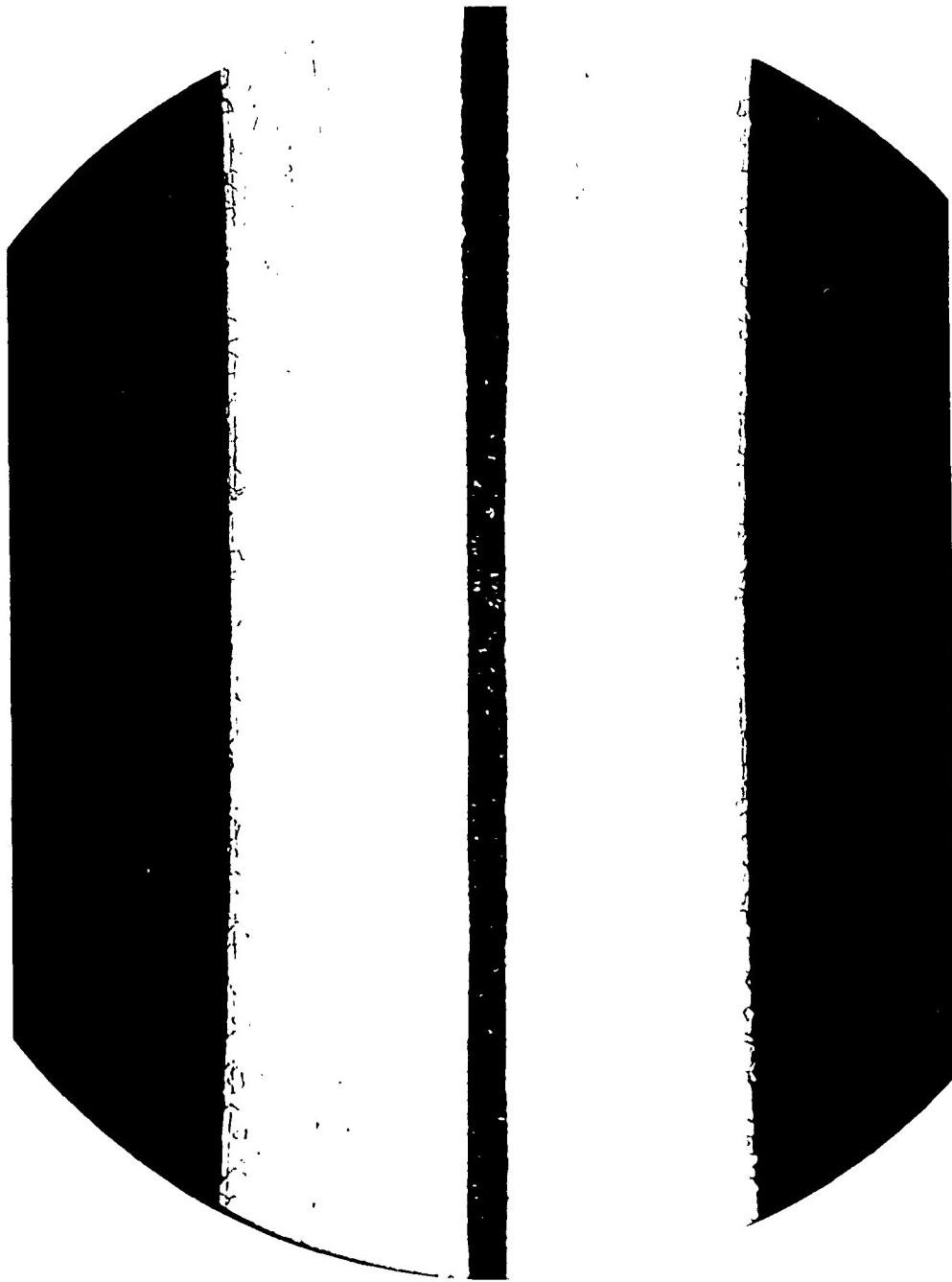
A photomicrograph of a typical TZM core to skin fillet
brazed with commercially pure titanium at 3100° F. (200x)

Fig. 48. TZM Core-to-Skin Fillet--Pure Titanium Braze



A D-36 T-joint brazed with 48Ti-48Zr-4Be at 2550° F. Erosion of the parent material is evidenced but is not considered severe. Specimen was etched to bring out grain structure of base metal. (75x)

Fig. 49. D-36 T-Joint--Ti-Zr-Be Braze



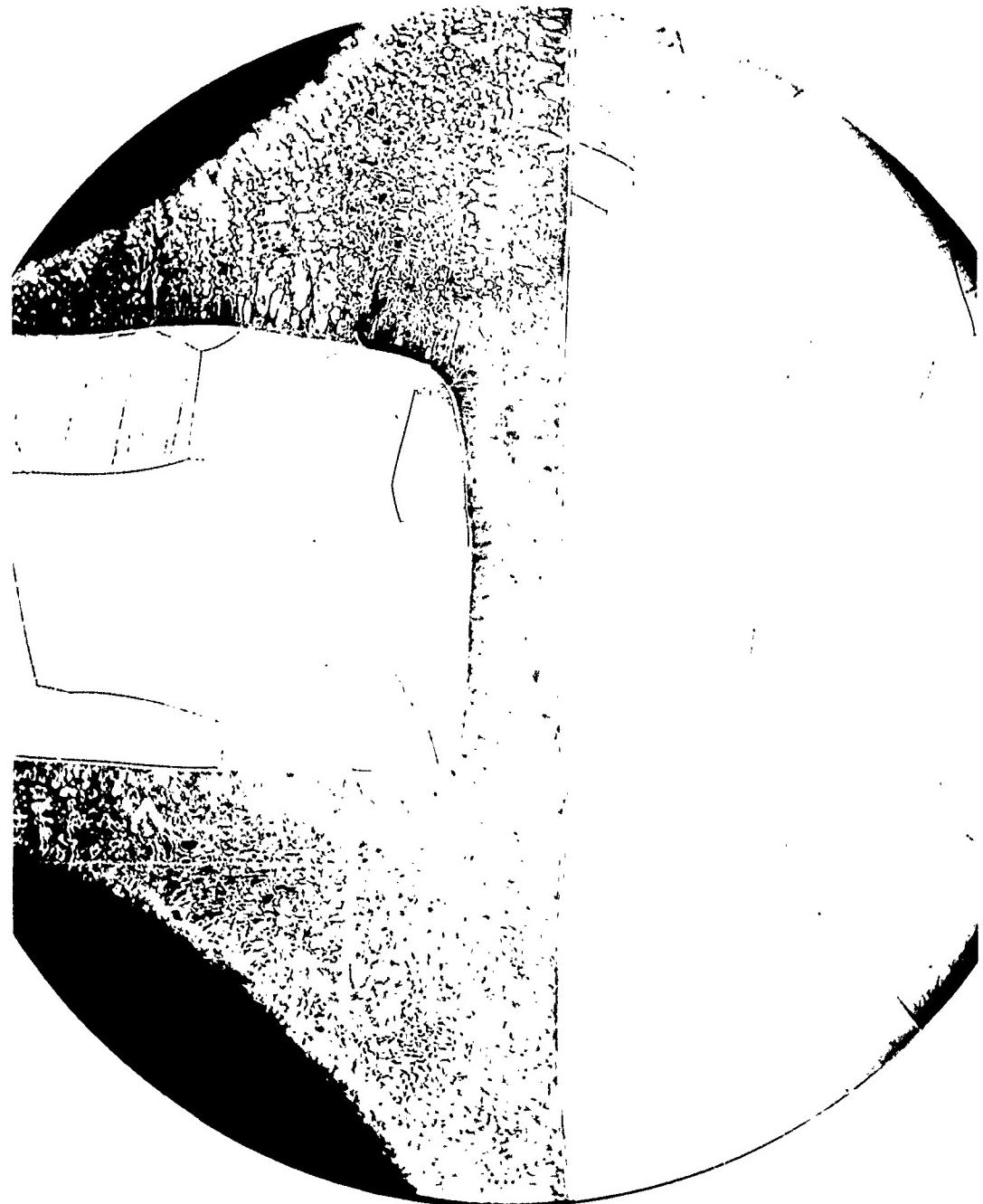
A photomicrograph of a D-36 laminate
brazed with 48Ti-48Zr-4 Be at 2550° F.
No void areas were noted in the
cross sections examined. (75x)

Fig. 50. D-36 Laminate--Ti-Zr-Be Braze



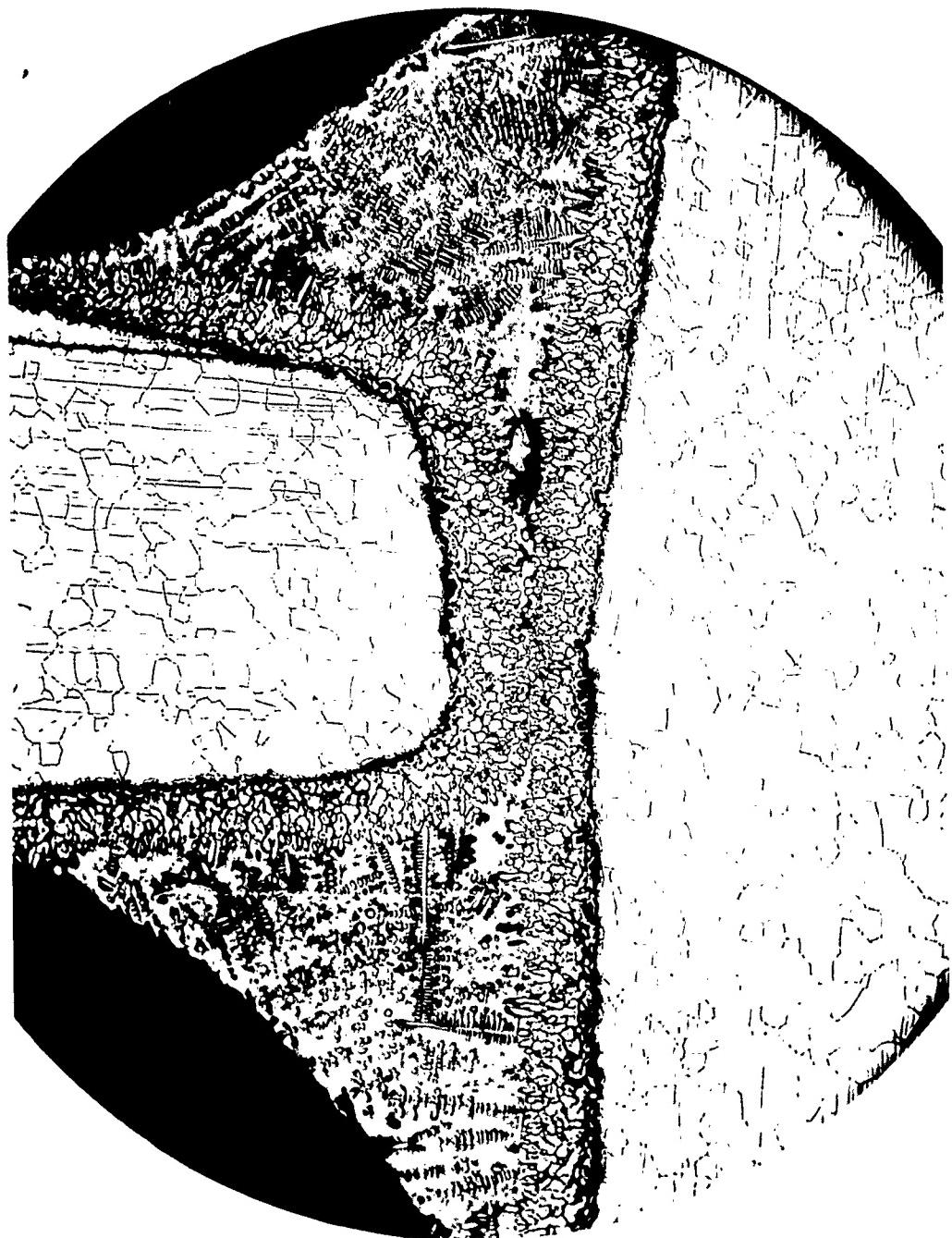
A D-36 T-joint brazed with pure palladium at 2900° F. Severe alloying has occurred between the base and filler material. This reaction has not been evidenced with either pure columbium or Cb-10Ti-10Mo. (75x)

Fig. 51. D-36 T-Joint--Pure Palladium Braze



Photomicrograph of a pure columbium T-joint brazed with pure palladium at 2900° F. A very narrow alloy zone is indicated with no erosion of the base material (75x)

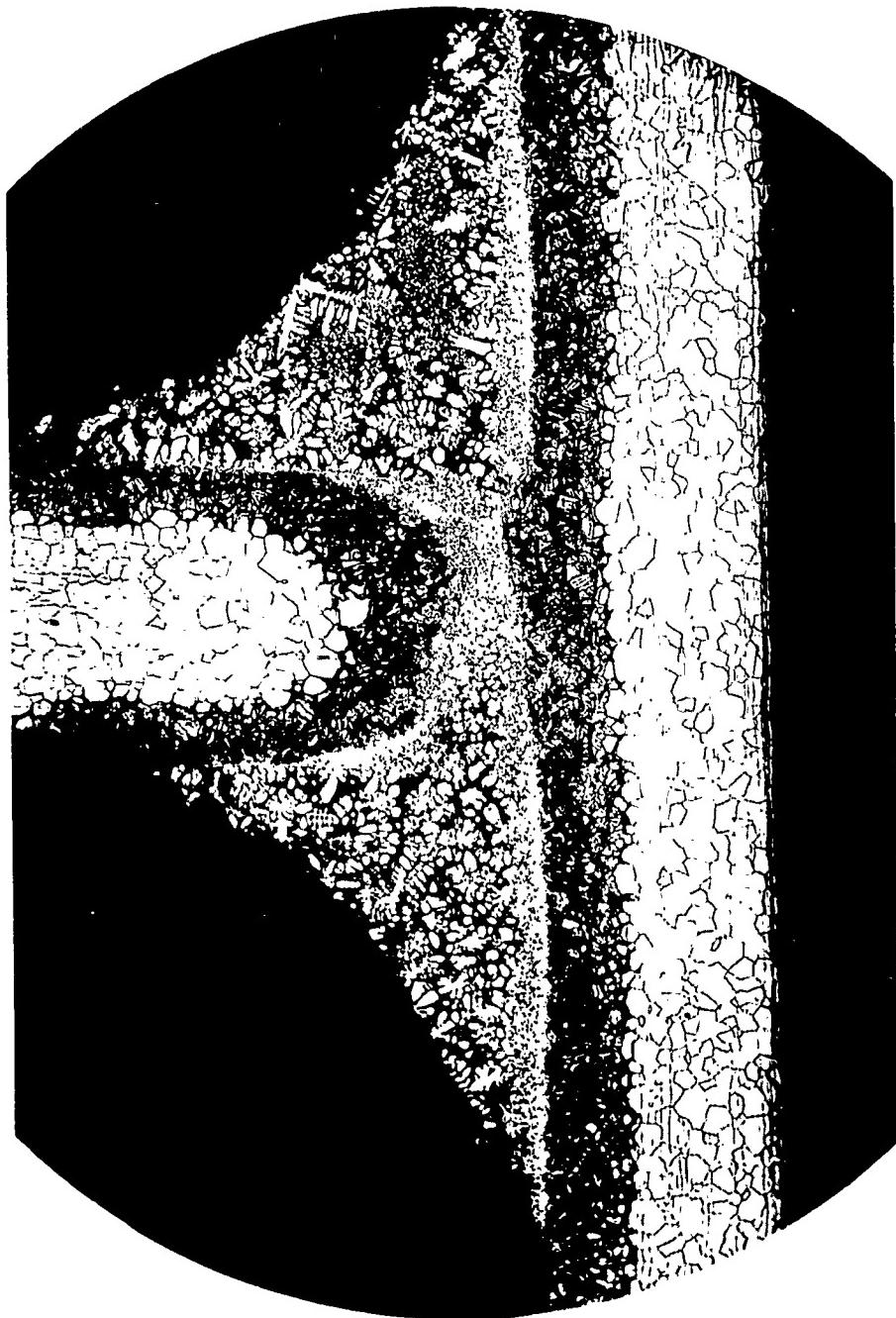
Fig. 52. Pure Columbium T-Joint--Pure Palladium Braze



A photomicrograph of a Cb-10Ti-10Mo
T-joint brazed with pure palladium
at 2900° F. Alloying has occurred but
is not as severe as noted in Fig. 51. (75x)

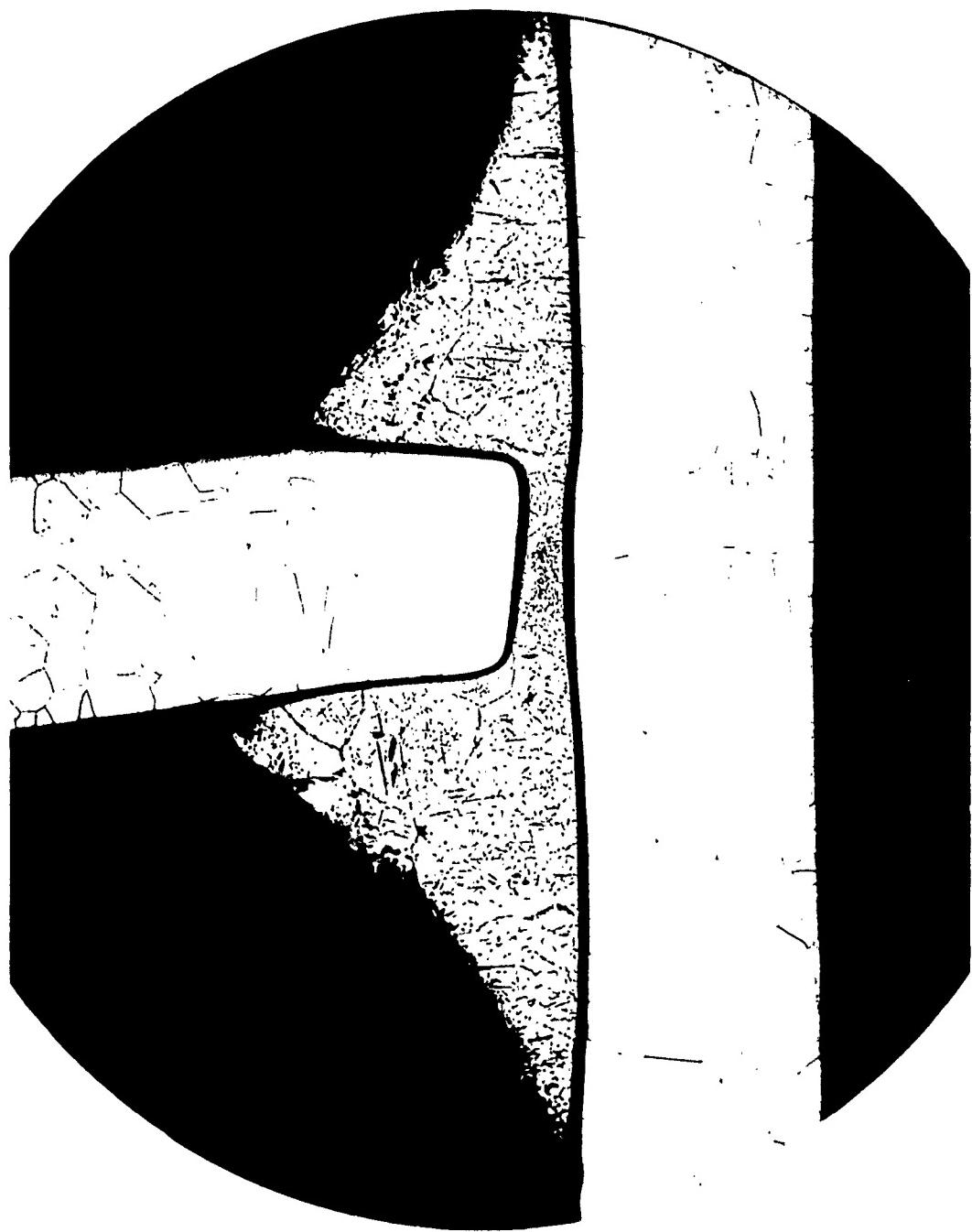
Fig. 53. Cb-Ti-Mo T-Joint--Pure Palladium Braze

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Photomicrograph of a D-36 T-joint brazed with 60 Pd-40Cu at 2250° F. Again, severe alloying with the base material is evidenced, which indicates the possibility of a low melting eutectic reaction occurring between the ternary Cb-Ti-Zr and Pd-Cu. (75x)

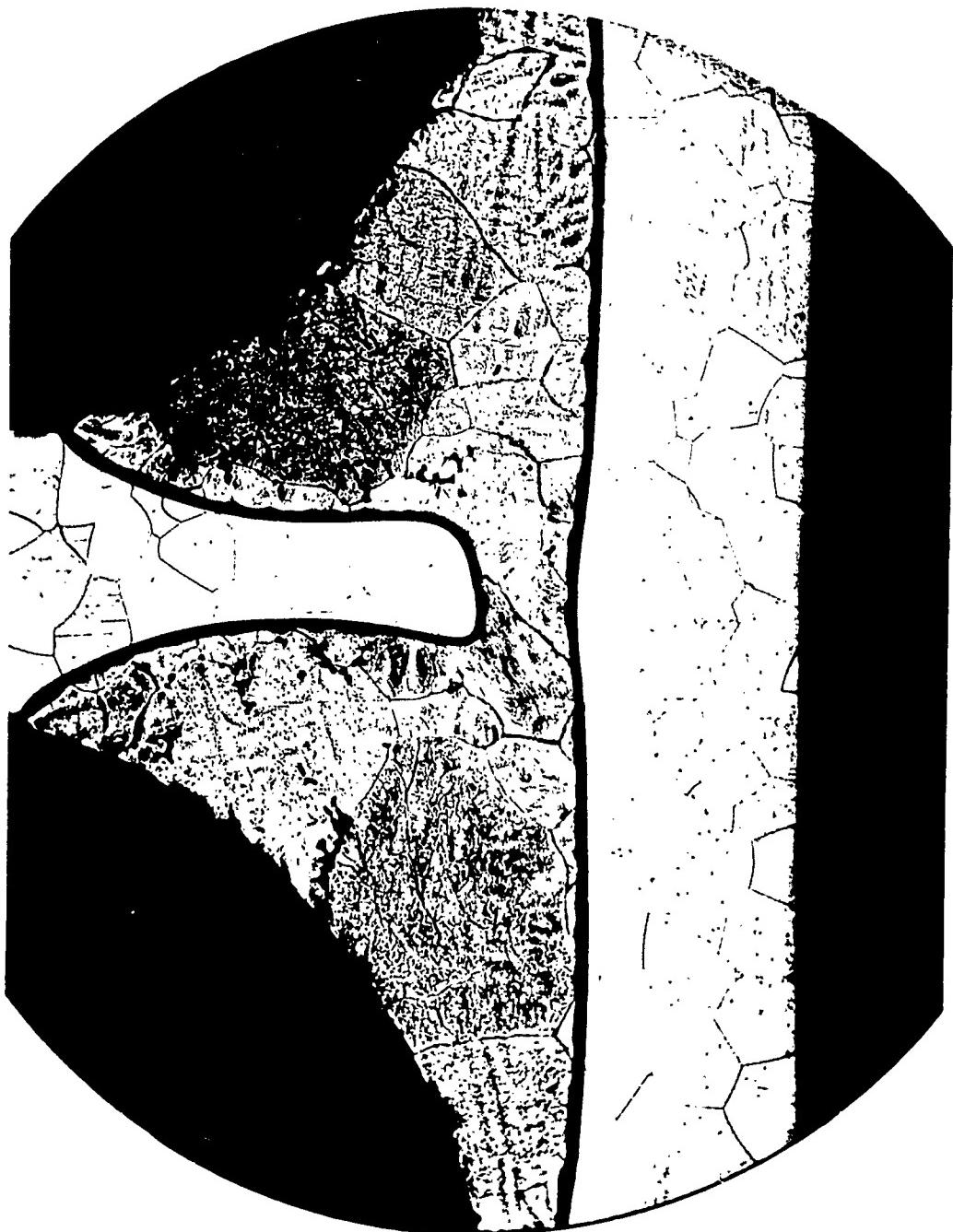
Fig. 54. D-36 T-Joint--Pd-Cu Braze



A photomicrograph of a D-36 T-joint
brazed with commercially pure
titanium at 3100° F. Filletting
action of the braze alloy is marginal
at this temperature. (75x)

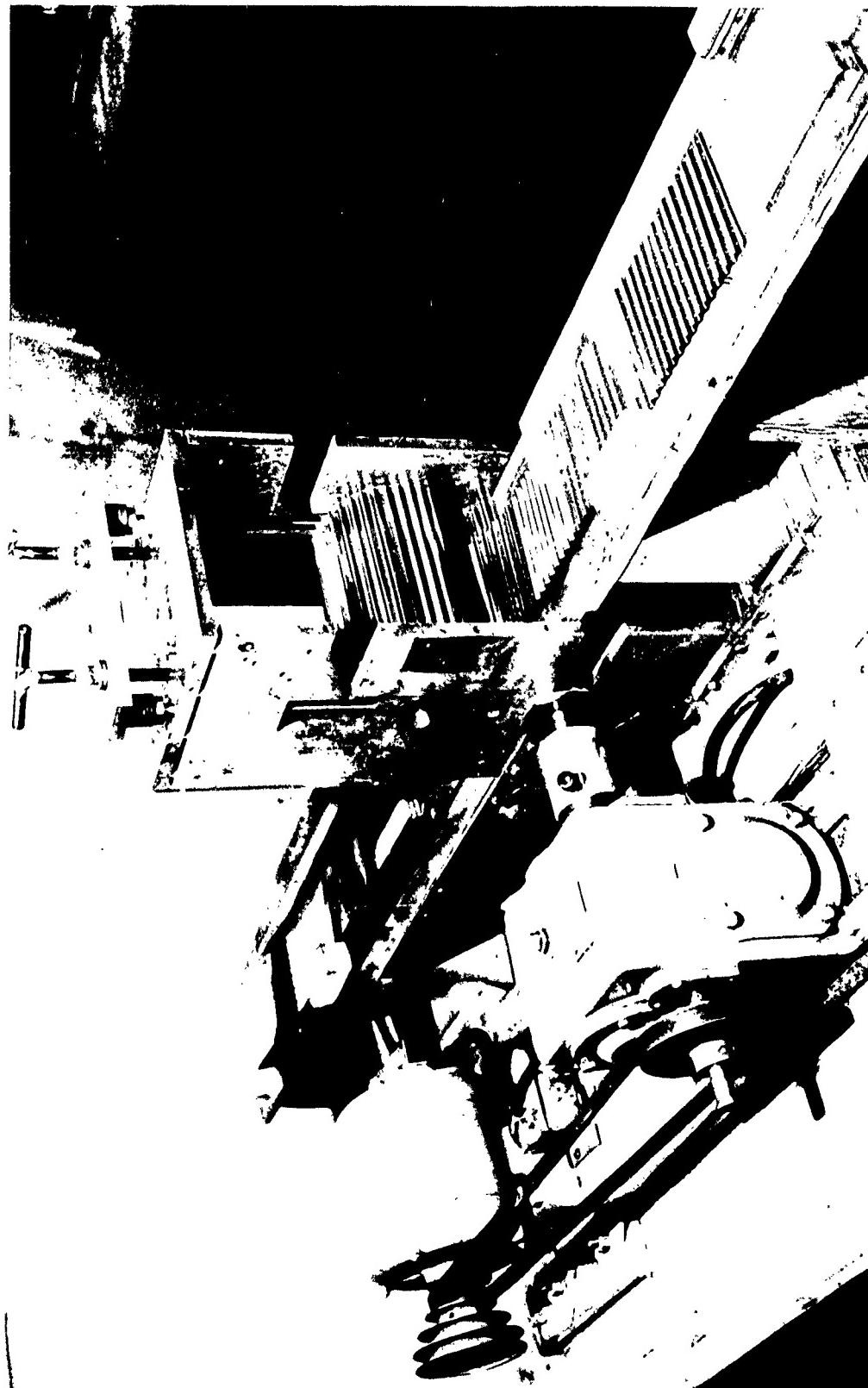
Fig. 55. D-36 T-Joint--Pure Titanium Braze

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A photomicrograph of a D-36 T-joint brazed with commercially pure titanium at 3200° F. Severe erosion of the parent material occurred as a result of the temperature increase from 3100° to 3200° F (cf. Fig. 55). (75x)

Fig. 56. D-36 T-Joint--Pure Titanium Braze



Honeycomb Core for Fabricating

Fig. 57. Corrugation Tool



Fig. 58. Renite Template for Inspecting Dimensional Correctness
of Corrugated Foil

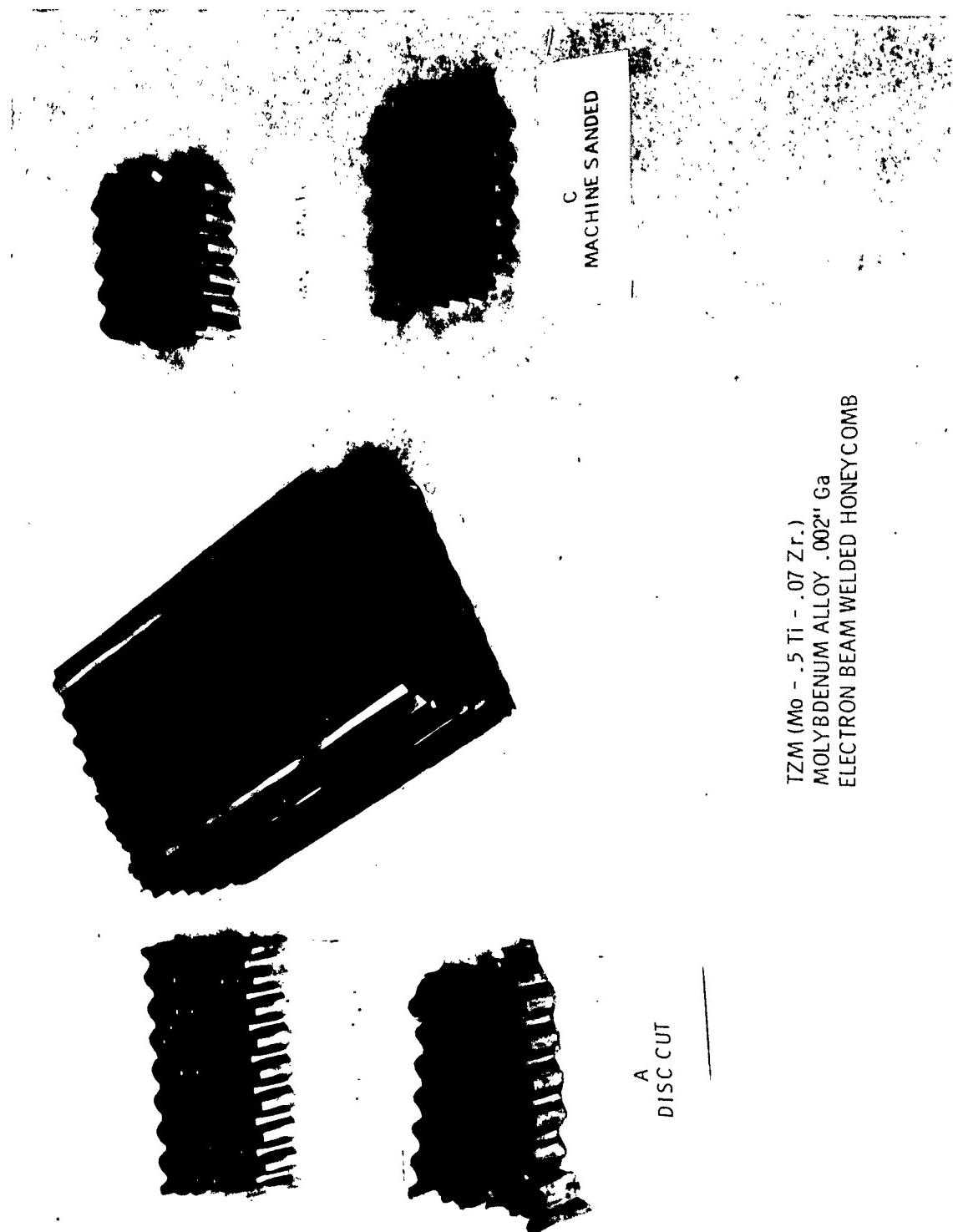
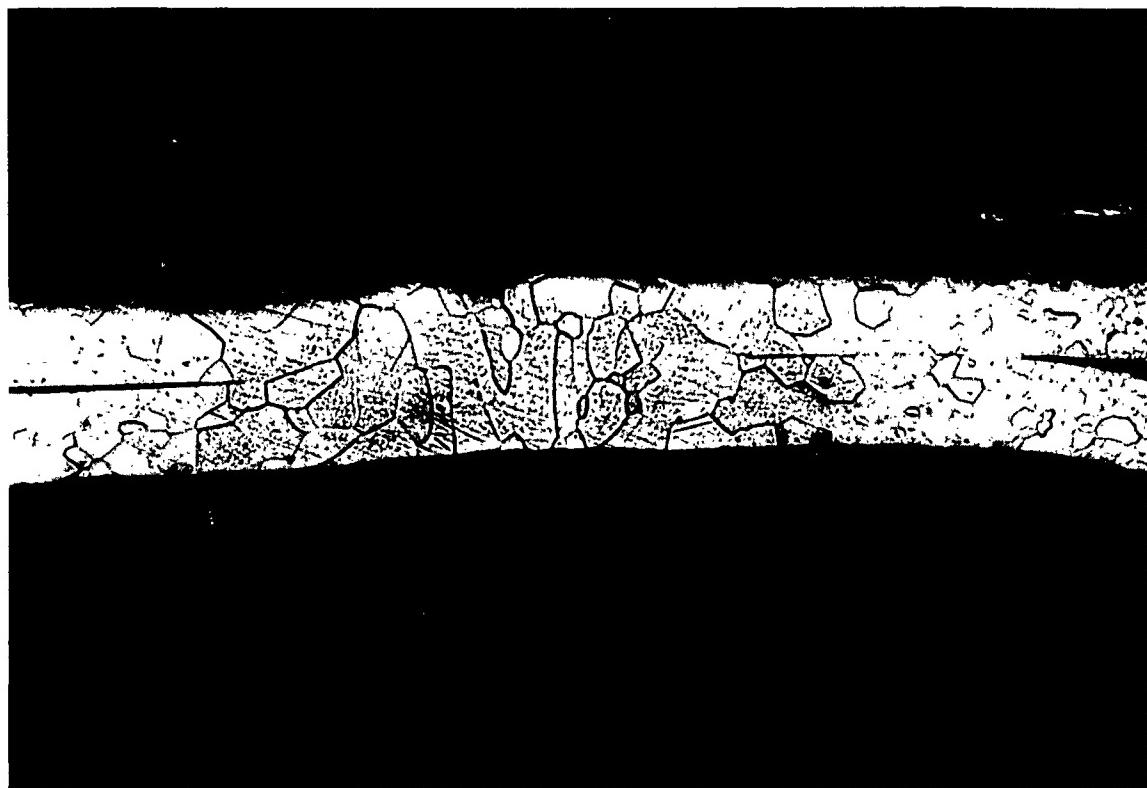


Fig. 59. Methods of Surfacing Honeycomb Material for Test Panels



Photomicrograph of cross section of TZM Molybdenum core welded by Electron Beam Method showing metallographic structure characteristics of weldment. (320x)

Fig. 60. Electron Beam Welding--TZM Molybdenum Core

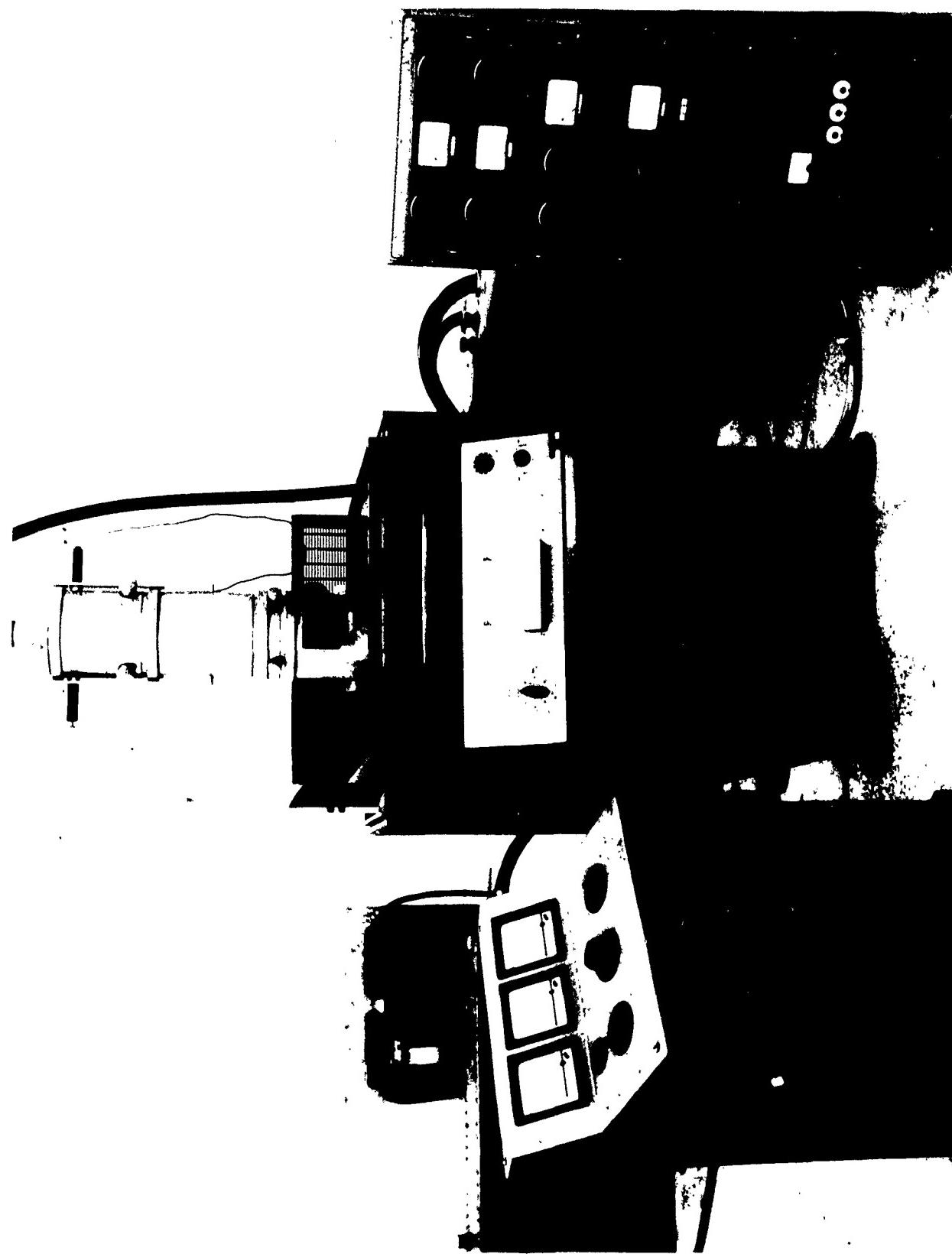


Fig. 61. Electron Beam Welder

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Fig. 62. Electron Beam Welding Chamber

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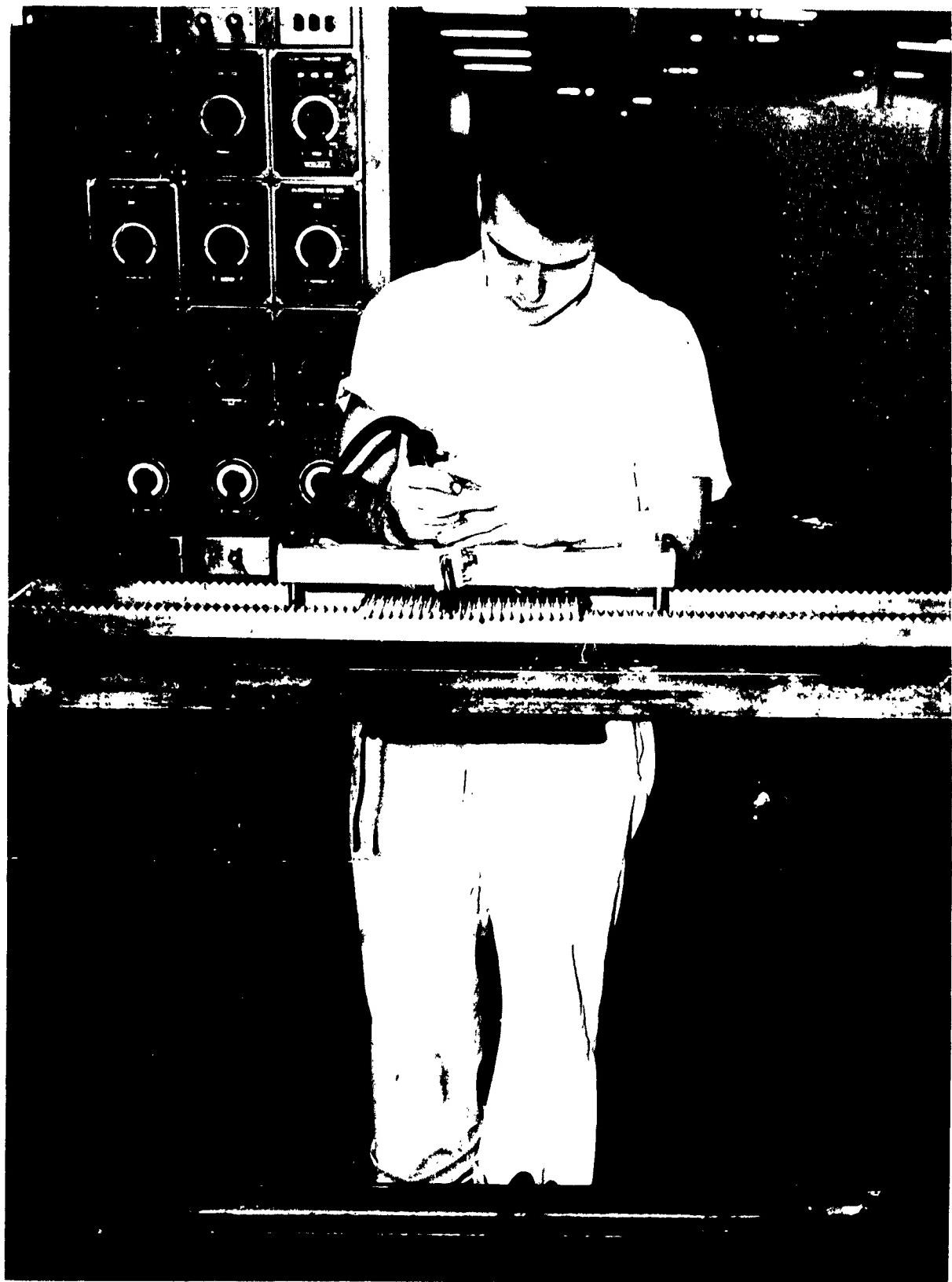


Fig. 63. Resistance Welding of Honeycomb Core

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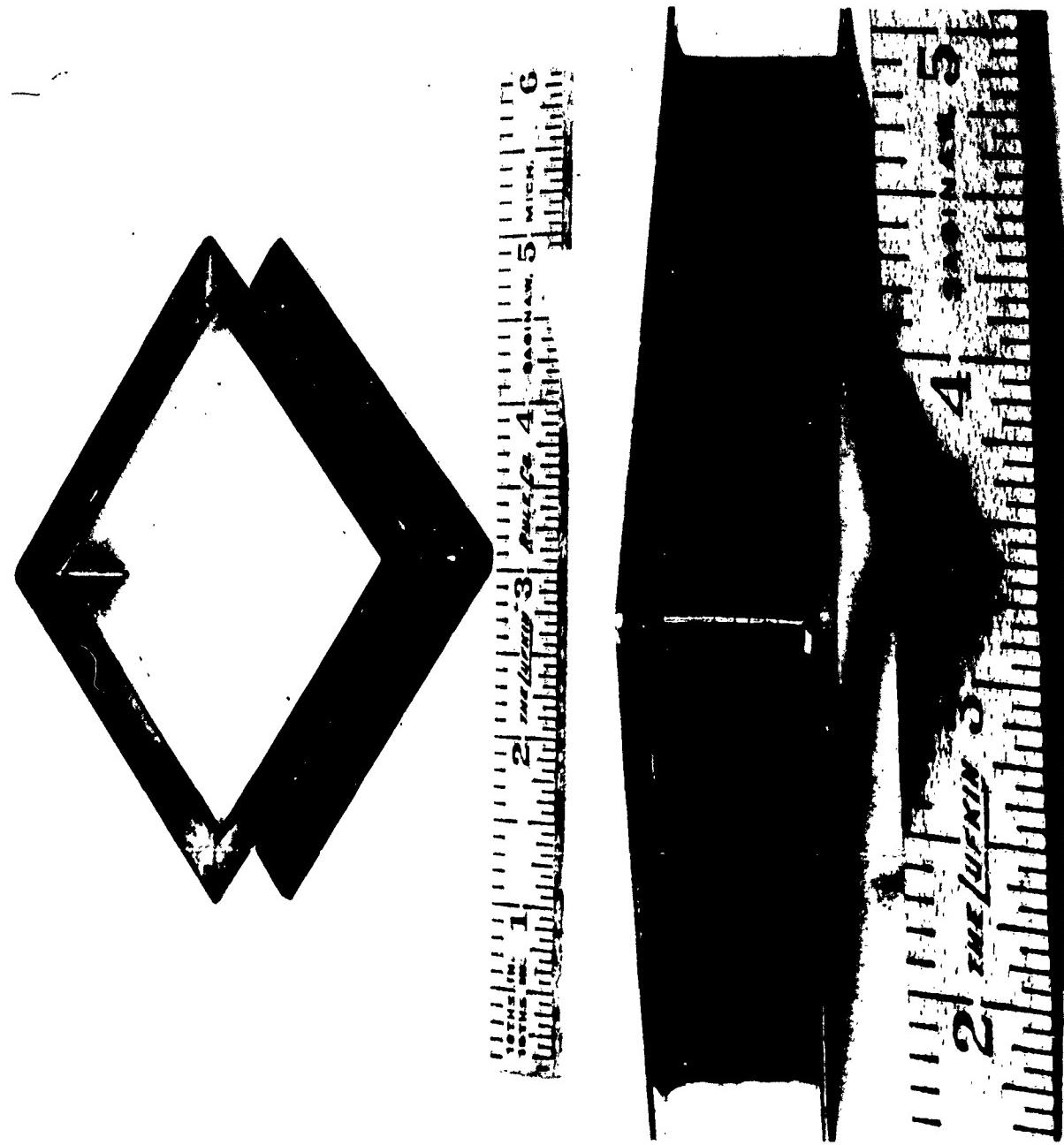


Fig. 64. Simulated Edge Members in Stainless Steel - Electron Beam Welded

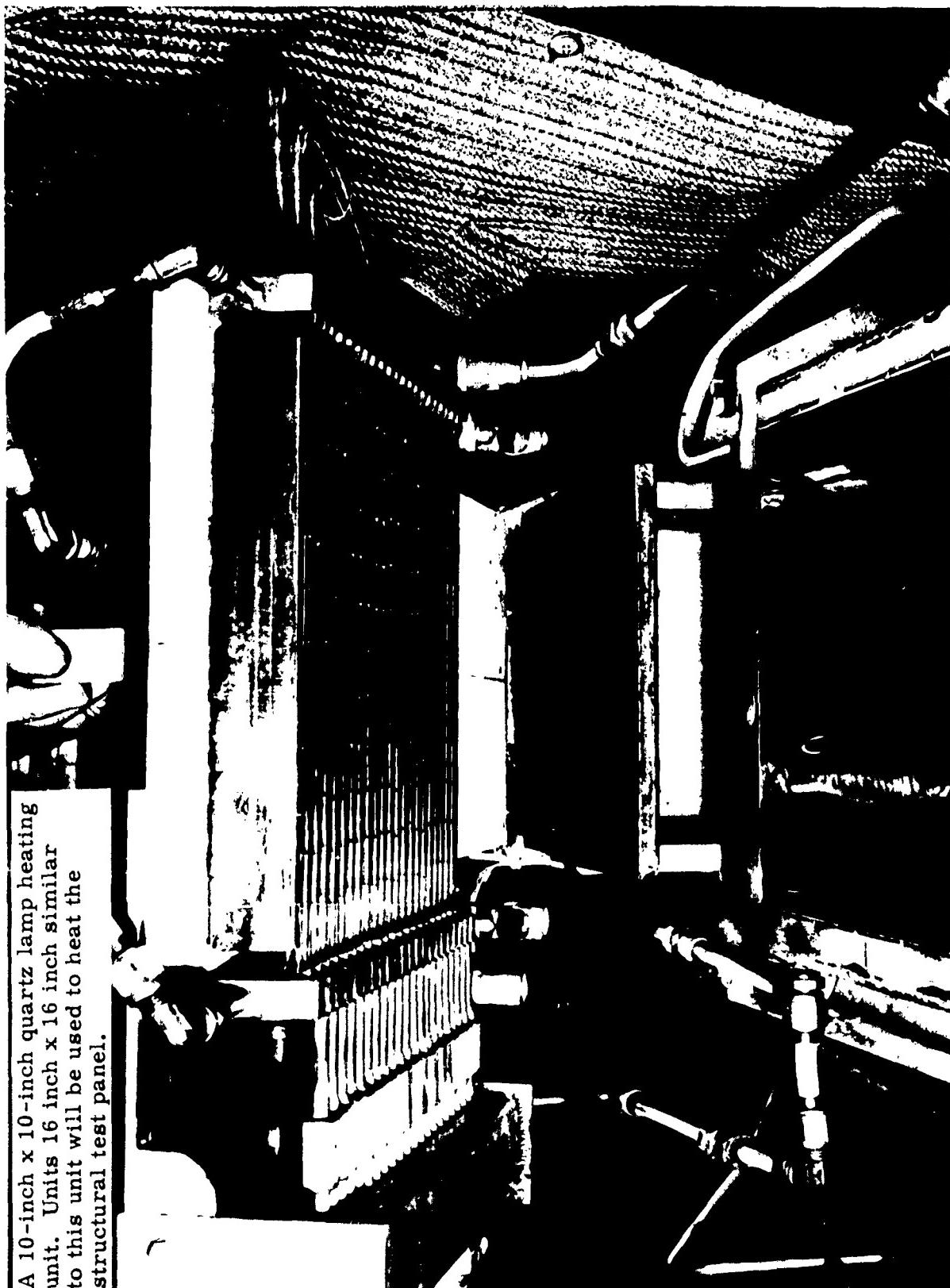


Fig. 65. Quartz Lamp Heating Unit

APPENDIX B

ANALYSIS OF THERMAL GRADIENT
THROUGH HONEYCOMB PANELS

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APPENDIX B

ANALYSIS OF THERMAL GRADIENT
THROUGH HONEYCOMB PANELSI. GENERAL DISCUSSION

With a heating cycle applied to the outer surface of a honeycomb panel, it is desired to determine the thermal gradient between the outer and inner faces of the panel. A procedure developed by Swann and Pittman was used to analyze the problem. This technical note [19,20] outlines a method for determining the effective thermal conductivity of honeycomb panels. Swann and Pittman analyzed the effective thermal conductivity at the panel's mean temperature during steady-state conditions.

In this analysis, steady-state conditions are assumed to exist during small time intervals, and transient heating conditions were analyzed by using small successive time increments. The effective thermal conductivity used in this analysis includes the three modes of heat transfer: radiation, conduction and convection. With the panel configuration given, and an inside surface temperature at the end of a time interval assumed, the effective thermal conductivity during that time interval can be determined. With this effective thermal conductivity, the inside surface temperature can be calculated by using a general heat balance equation. If the assumed and calculated values of the inside surface temperatures do not agree, the procedure is repeated until they do agree. Once these two inside temperatures are in agreement, an inside surface temperature at the end of the next time increment is assumed, and the above procedure is repeated.

II. THE SPECIFIC PROBLEM

For any given heating cycle applied to the outer surface of molybdenum or columbium honeycomb panels, determine the inner surface temperature at various times.

Given:

- (1) Outer surface temperature ($^{\circ}$ F) as a function of time.
- (2) Height of honeycomb core (L)
- (3) Cell diameter (D)
- (4) Weight of inner face per square foot (W_s)
- (5) Weight of core per square foot (W_c)
- (6) Solidity of core (ΔA)
Density of core/density of skin

- (7) Stefan-Boltzmann constant (σ)
 $0.174 \times 10^{-8} \text{ Btu}/\text{ft}^2 \cdot \text{hr} \cdot {}^{\circ}\text{R}^4$
- (8) Initial inner surface temperature (T_{i1})
- (9) Thermal conductivity of molybdenum or columbium
- (10) Specific heat of molybdenum or columbium
- (11) Emissivity of molybdenum or columbium

III. SOLUTION

- (1) Determine outer temperature (T_o) at each 0.50 second interval
- (2) Determine the mean panel temperature during first time interval
- (3) Determine thermal conductivity, specific heat, and emissivity of core material at panel's mean temperature
- (4) Assume inner surface temperature (T_{i2})
- (5) Using $\bar{T}_o = (\sigma e L / k \Delta A)^{1/3} T_o$
and $\bar{T}_{i2} = (\sigma e L / k \Delta A)^{1/3} T_{i2}$,
determine \bar{T}_o and \bar{T}_{i2}
- (6) Using the equation:

$$\frac{k_e}{k \Delta A} = 1.0$$

$$+ 0.664 (\lambda + 0.3)^{-0.69} e^{1.63 (\lambda + 1)^{-0.89}}$$

$$(\bar{T}_o^2 + \bar{T}_{i2}^2) (\bar{T}_o + \bar{T}_{i2})$$

where $\lambda = L/D$

Note:

The expression above was found by a process of trial and error; it is based upon 1,200 calculated values of effective thermal conductivity ratio, with a maximum deviation of 6.5 %.

determine $k_e/k \Delta A$

- (7) Calculate k_e
- (8) Calculate the heat flow (q) using:

$$q = \frac{k_e}{L} (T_o - T_{i2})$$

- (9) Using the heat balance equation:

$$q\Delta t = W_e (C_p) (T_{i2} - T_{i1})$$

where:

W_e = Effective weight

$$= W_e / 4 + W_s$$

T_{i1} = Temperature of inner surface at beginning of the time increment

T_{i2} = Temperature of inner surface at end of the time increment

determine T_{i2}

- (10) Compare the (T_{i2}) calculated in step 9 with the assumed value. If the assumed (T_{i2}) does not agree with the calculated (T_{i2}), assume another value of (T_{i2}) and repeat steps 5 through 10.

- (11) If the assumed (T_{i2}) does agree with the calculated (T_{i2}), go to the next time increment. Let (T_{i1}) equal the previous (T_{i2}) for the new time increment. Repeat steps 2 through 10.

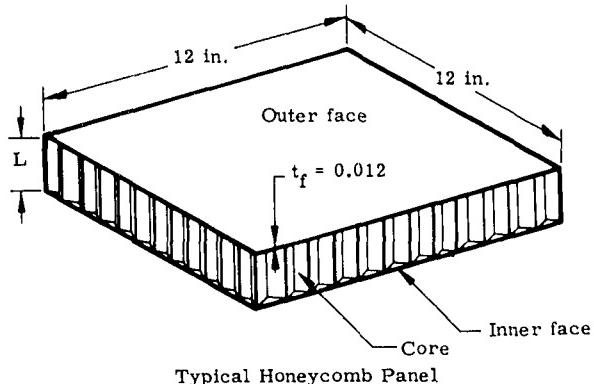
The method of solution described previously was programmed in FORTRAN. FORTRAN is an automatic coding system with a language that closely resembles the language of mathematics. The FORTRAN language is a concise, convenient means of stating the steps to be carried out by IBM computers in solving many types of problems.

The thermal gradient through a honeycomb panel was determined for two different thermal cycles for both the molybdenum and the columbium honeycomb panels. The thermal cycles selected represent typical aerospace vehicle design criteria. The program procedures for one thermal cycle and the molybdenum alloy panel are presented in this report. The results of both cycles on both materials are plotted in Figs. 27, 28, 29, and 30 of Appendix A.

IV. SAMPLE PROBLEM

What is the temperature of the inside face of a molybdenum honeycomb panel (shown below) at any time if at ($t = 0$) both surfaces are assumed to be at 2440° F, and the outside temperature starts to increase at the rate of 50° F/sec until 2750° F is reached? The outside face is held at 2750° F for 10 seconds then decreased at a rate of 15° F/sec until $t = 32.0$ seconds.

$$L = 1/4, 3/8, 1/2, 5/8
3/4, 7/8, 1.0, 1.5$$



A. SOLUTION

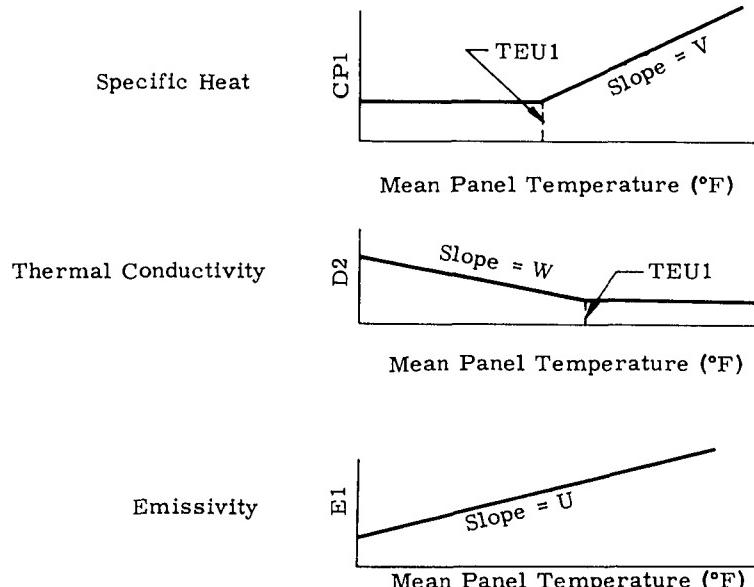
The method of solution described previously was programmed in FORTRAN.

The program was written in floating point, and the input was represented as shown on the sketch on the next page.

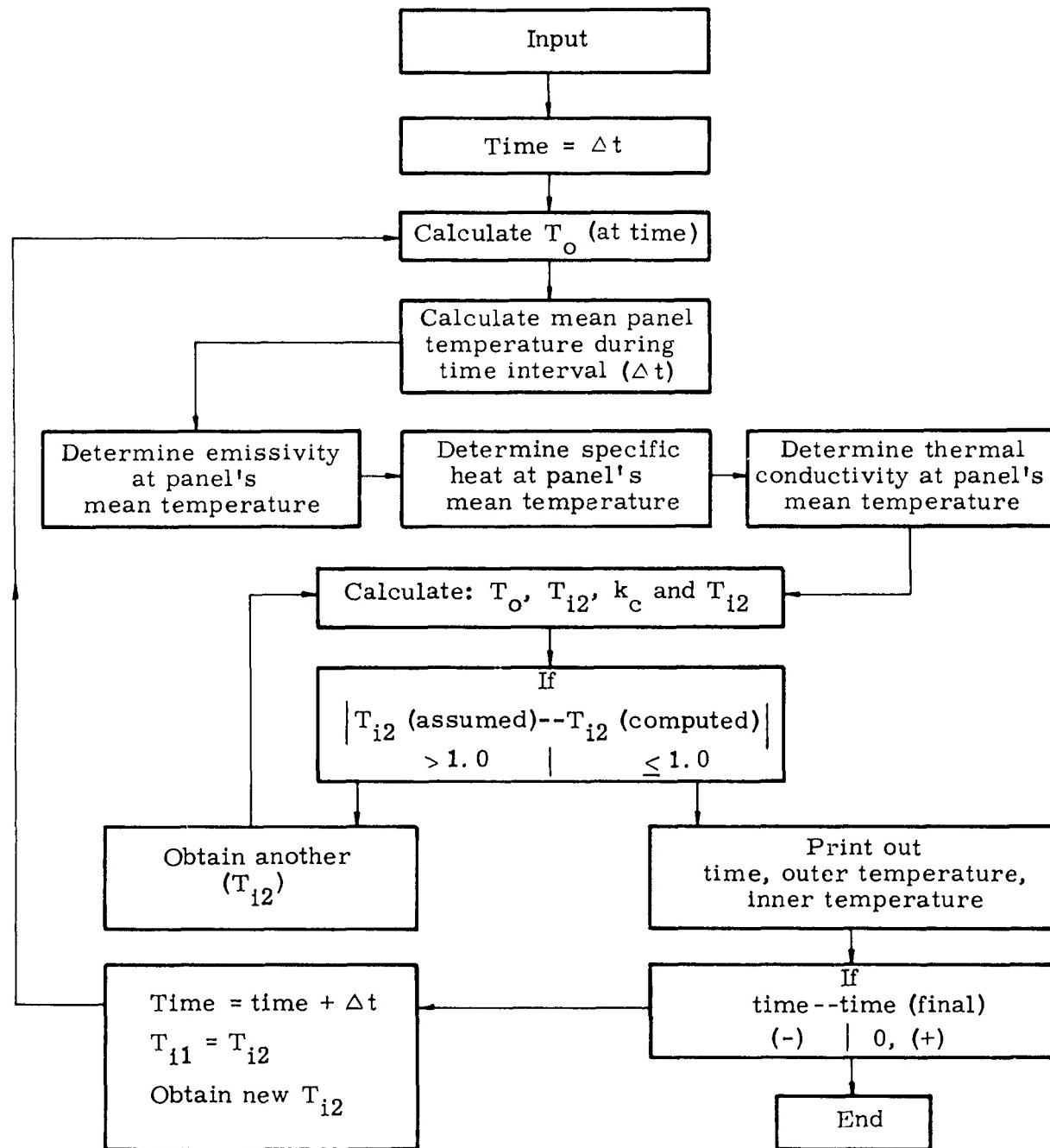
B. FLOATING POINT INPUT VALUES

- (1) H = 0.0208, 0.0312, 0.0417, 0.0520, 0.0625, 0.0729, 0.0833, 0.1250, and 0.1667. Core thickness (ft)
- (2) THIS = 0.001 thickness of inside face (ft)
- (3) DENS = 637.0 density of face (lb/ft³)
- (4) DENC = 10.7 density of core (lb/ft³)
- (5) DIA = 0.0156 core diameter (ft)
- (6) TEI₁ = 2440.0 initial inside face temperature (°F)
- (7) TEIA = 2443.0 assumed inside face temperature at the end of the first time increment (°F)
- (8) BOL = 0.174×10^{-8} Stefan-Boltzmann constant (Btu/ft·hr·°R⁴)
- (9) U = 58.50×10^{-6} slope of emissivity curve (per °F)
- (10) E1 = 0.024 intersection of emissivity curve

Physical Properties of Molybdenum



- | | | | |
|-----------|-----------------------------------------------------------------------------------------------------------|---------------|------------------------------------------------------------------------------------|
| (11) V | = 17.50×10^{-6} slope of specific heat curve ($\text{Btu/lb} \cdot {}^{\circ}\text{F}^2$) | (18) R | = 50.0 rate of temperature increase of outer face (${}^{\circ}\text{F/sec}$) |
| (12) CP1 | = 0.064 constant specific heat ($\text{Btu/lb} \cdot {}^{\circ}\text{F}$) | (19) C | = 2440.0 initial outer face temperature (${}^{\circ}\text{F}$) |
| (13) TEU1 | = 1340.0 temperature at which specific heat curve changes slope (${}^{\circ}\text{F}$) | (20) B | = 2750.0 constant outer face temperature beginning at T_{i1} and ending T_{i2} |
| (14) W | = -14.05×10^{-3} slope of thermal conductivity curve ($\text{Btu/hr-ft-}{}^{\circ}\text{F}^2$) | (21) S | = 15.00 rate of temperature decrease on outer face (${}^{\circ}\text{F/sec}$) |
| (15) D1 | = 40.50 constant thermal conductivity ($\text{Btu/hr-ft-}{}^{\circ}\text{F}$) | (22) T_{i1} | = 6.20 time at which temperature on outer face stops increasing (sec) |
| (16) D2 | = 86.00 intersection of thermal conductivity curve ($\text{Btu/hr-ft-}{}^{\circ}\text{F}$) | (23) T_{i2} | = 16.20 time at end of constant heating of outer face (sec) |
| (17) TEU2 | = 3240.0 temperature at which thermal conductivity changes slope (${}^{\circ}\text{F}$) | (24) T_{i3} | = 32.00 time at end of thermal shock (sec) |
| | | (25) DT | = 0.50 time increment (sec) |



Flow Diagram

MARTIN FORTRAN PROGRAMMING FORM

ANALYST _____

E-661

TITLE HEAT FLOW THROUGH MOLYBDENUM HONEYCOMB PANELS		DATE _____	
JOB NO. _____		SHEET 1 _____ OF _____	
ITEM	1 . 2 . 3 . 4 . 5 . 6 . 7 . 8 . 9 . 10 . 11 . 12 . 13 . 14 . 15 . 16 . 17 . 18 . 19 . 20 . 21 . 22 . 23 . 24 . 25 . 26 . 27 . 28 . 29 . 30 . 31 . 32 . 33 . 34 . 35 . 36 . 37 . 38 . 39 . 40 . 41 . 42 . 43 . 44 . 45 . 46 . 47 . 48 . 49 . 50 . 51 . 52 . 53 . 54 . 55 . 56 . 57 . 58 . 59 . 60 . 61 . 62 . 63 . 64 . 65 . 66 . 67 . 68 . 69 . 70 . 71 . 72 . 73 . 74 . 75 . 76 . 77 . 78 . 79 . 80		
	3.5 TEIC=TEII		
	3.6 LF(TEIC-TEIA) 3.7 . 4.1 . 3.8		
	3.7 LF(TEIC-TEIA+1.0) 3.9 . 4.1 . 4.1		
	3.8 LF(TEIC-TEIA-1.0) 4.1 . 4.1 . 3.9		
	3.9 TEIA=TEIC-(TEIC-TEIA)*.5		
	4.0 G• T• 3.B		
	4.1 TYPE 4.2 . T. T• TEIC		
	4.2 FORMAT(8H TIME = E11.4 . 13H OUTER TEMP.=E11.4 . 12H INNER TEMP.=E11.4)		
	4.3 LF(T-TI3) 45.44 . 44		
	4.4 G• T• 1		
	4.5 TEII=TEIC		
	4.6 LF(T• -TEII) 4.7 . 4.7 . 4.9		
	4.7 TEIA=TEII-2.0		
	4.8 G• T• 5.0		
	4.9 TEIA=TEII+2.0		
	5.0 T=T+DT		
	5.1 G• T• 7		
	END		

APPENDIX C

STRUCTURAL DESIGN OF HEAT SHIELDS

ER 12249

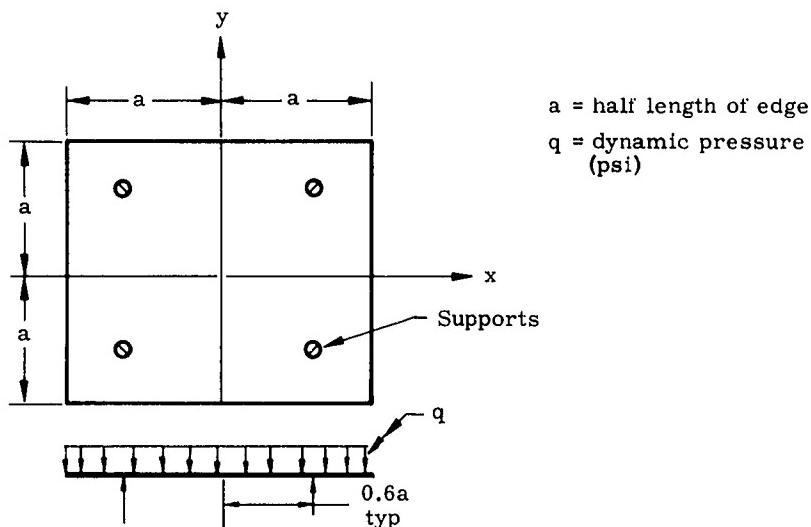
APPENDIX C

STRUCTURAL DESIGN OF HEAT SHIELDS

I. BASIC PROBLEM

The basic structural problem is that of a plate supported at four points.

difference equations for the plate deflections. The effects of the shear in the plate were neglected (Ref. 1). Such a solution with a grid spacing of $a/5$ is very reasonable for panel design purposes.

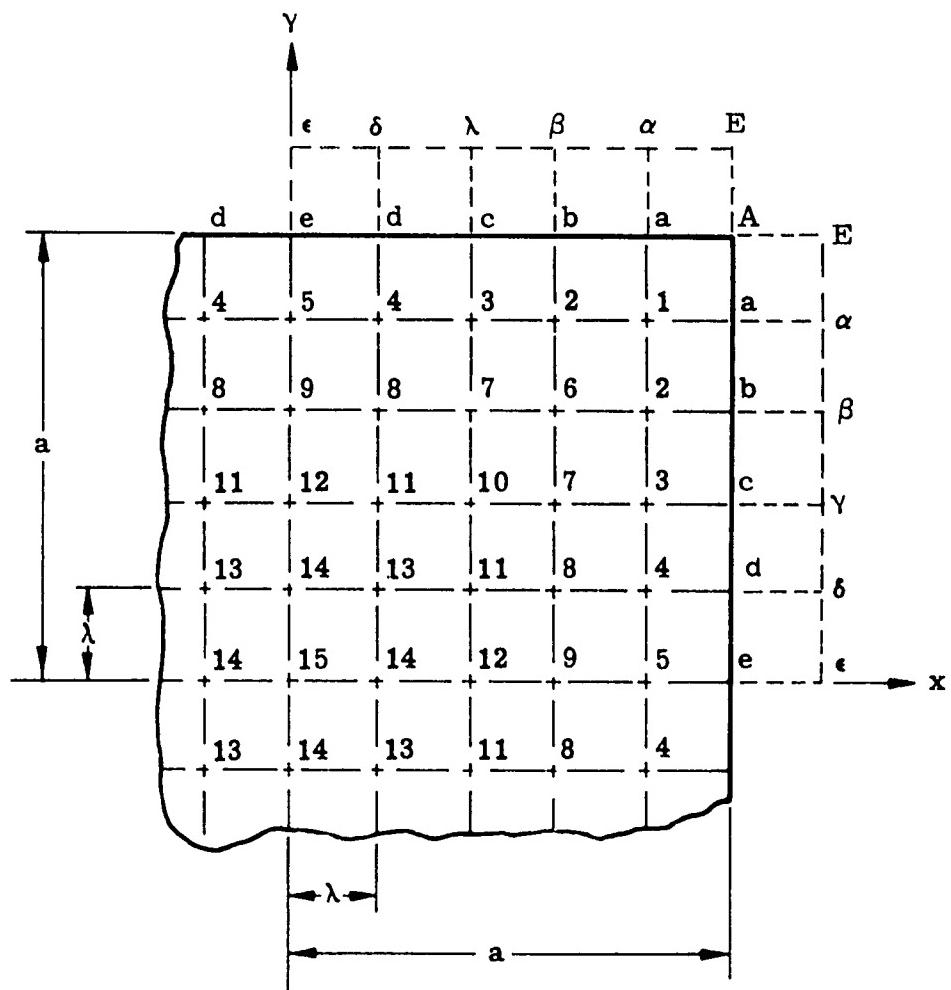


A solution was obtained by making finite difference approximations of the governing differential equations and then algebraically solving the finite

Ref. 1. Appendix B, Section F, Structures Report, Vol. III Dyna-Soar Project, Ws 454L Contract No. AF33(600)-37705, Martin ER-10373 Classified Secret, Work done by Bell in Study contract.

II. FINITE DIFFERENCE GRID
USED IN SOLUTION

Support reactions are at Point 6. All edges are free. The panel is symmetrical about the x and y axes.



III. PLATE DEFLECTION VALUES

Solution of the finite difference equations gave the following values for the deflection of the plate:

w_1	= 3.155K	w_a	= 5.5239K
w_2	= 1.5925K	w_b	= 3.3672K
w_3	= 2.7545K	w_c	= 3.4374K
w_4	= 4.3409K	w_d	= 4.1672K
w_5	= 4.9361K	w_e	= 4.2827K
w_6	= 0.00	w_α	= 7.5432K
w_7	= 2.6402K	w_β	= 4.4738K
w_8	= 5.0852K	w_γ	= 3.9223K
w_9	= 5.9972K	w_δ	= 4.1779K
w_{10}	= 4.7453K	w_ϵ	= 3.6987K
w_{11}	= 6.9003K	w_E	= 12.164K
w_{12}	= 7.7546K	w_A	= 8.441K
w_{13}	= 8.6913K		
w_{14}	= 9.4163K		
w_{15}	= 10.089K		

where

$$K = \frac{q\lambda^4}{D}$$

$$\lambda = \frac{a}{5}$$

$$D = \frac{EI}{1 - \mu^2}$$

IV. BENDING MOMENTS

From pure bending theory of a flat plate, the bending moment at any point in a plate in the x and y directions is

$$M_{x_O} = -D \left(\frac{\partial^2 w_O}{\partial x^2} + \mu \frac{\partial^2 w_O}{\partial y^2} \right)$$

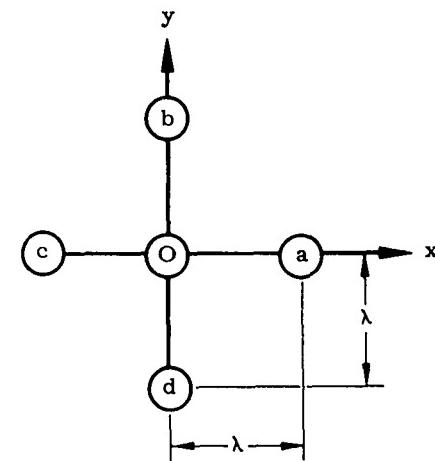
$$M_{y_O} = -D \left(\frac{\partial^2 w_O}{\partial y^2} + \mu \frac{\partial^2 w_O}{\partial x^2} \right)$$

The finite difference approximation for $\frac{\partial^2 w_O}{\partial y^2}$ and $\frac{\partial^2 w_O}{\partial x^2}$ is

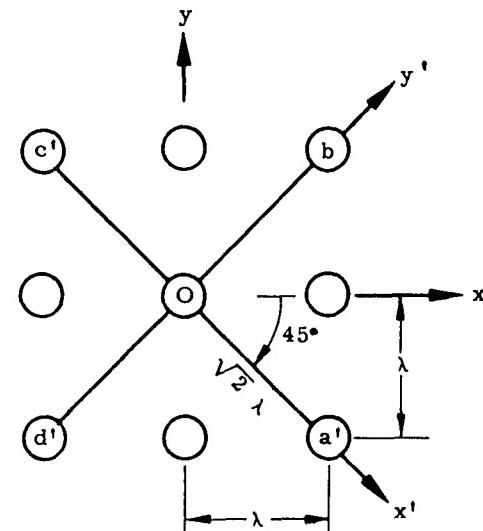
$$\frac{\partial^2 w_O}{\partial x^2} = \frac{1}{\lambda^2} (w_a - 2w_O + w_c)$$

$$\frac{\partial^2 w_O}{\partial y^2} = \frac{1}{\lambda^2} (w_b - 2w_O + w_d)$$

where "o" is the point in question. The terms w_a , w_b , w_c , w_d , and w_o designate respectively the deflection function of the points to the right, above, left, below and of the point in question. The deflection functions for this case are given in the column at the left.



The bending moments at an angle of 45° to the x-x and y-y axes can be found by using a rotated grid as shown below



then M at a plane of 135° from x-x axis is

$$M_{y'_O} = -D \frac{\partial^2 w_O}{\partial y'^2} + \mu \frac{\partial^2 w_O}{\partial x'^2}$$

$$M_{x'} = -D \left(\frac{\partial^2 w_o}{\partial x'^2} + \mu \frac{\partial^2 w_o}{\partial y'^2} \right)$$

where

$$\frac{\partial^2 w_o}{\partial x'^2} = \frac{1}{2\lambda^2} (w_a' - 2w_o + w_c')$$

$$\frac{\partial^2 w_o}{\partial y'^2} = \frac{1}{2\lambda^2} (w_b' - 2w_o + w_d')$$

V. ANALYSIS OF PLATE

- (1) Find $M_{x'}$ and $M_{y'}$ at Point 15

$$M_{x'} = M_{y'} = -D \left(\frac{\partial^2 w_o}{\partial x'^2} + \mu \frac{\partial^2 w_o}{\partial y'^2} \right)$$

$$\frac{\partial^2 w_o}{\partial x'^2} = \frac{\partial^2 w_o}{\partial y'^2} = \frac{1}{2\lambda^2} (2w_{15} - 2w_{13})$$

$$\begin{aligned} M_{x'} &= -D \left\{ (1 + \mu) \left[\frac{1}{\lambda^2} (w_{15} - w_{13}) \right] \right. \\ &= \left. \frac{D(1 + \mu)}{\lambda^2} (w_{15} - w_{13}) \right\} \end{aligned}$$

$$w_{15} - w_{13} = +1.3977K$$

$$M_{x'} = \frac{D(1 + \mu)}{\lambda^2} \left(1.3977 \frac{q\lambda^4}{D} \right)$$

$$M_{x'} = +1.3977 \lambda^2 (1 + \mu) q$$

The plus sign indicates positive moment, positive moment causes compression in the outer face.

- (2) Find $M_{y'}$ at Point 6

$$M_{y'} = -D \left(\frac{\partial^2 w_o}{\partial y'^2} + \mu \frac{\partial^2 w_o}{\partial x'^2} \right)$$

$$\frac{\partial^2 w_o}{\partial y'^2} = \frac{1}{2\lambda^2} [3.155K - 2(0) + 4.7453K]$$

$$= \frac{1}{2\lambda^2} [7.9003K]$$

$$\frac{\partial^2 w_o}{\partial x'^2} = \frac{1}{2\lambda^2} [2.7545K - 2(0) + 2.7545K]$$

$$= \frac{1}{2\lambda^2} [5.509K]$$

$$M_{y'} = -D \left[\frac{1}{2\lambda^2} (7.9003K) + \frac{\mu}{2\lambda^2} (5.509) \right]$$

$$M_{y'} = -\frac{D}{2\lambda^2} \left(\frac{q\lambda^4}{D} (7.9003 + 5.509\mu) \right)$$

$$M_{y'} = -\frac{1}{2} q\lambda^2 [7.9003 + 5.509\mu]$$

The minus sign indicates negative moment, negative moment causes tension in the outer face.

- (3) The moments found in Parts 1 and 2 are in lb/in. of width. To find the stress in the facing use,

$$f = \frac{Mc}{I}$$

where

$$c = \frac{h}{2}$$

$$I = \frac{1}{2} t_f h^2$$

$$\frac{c}{I} = \frac{1}{t_f h}$$

or

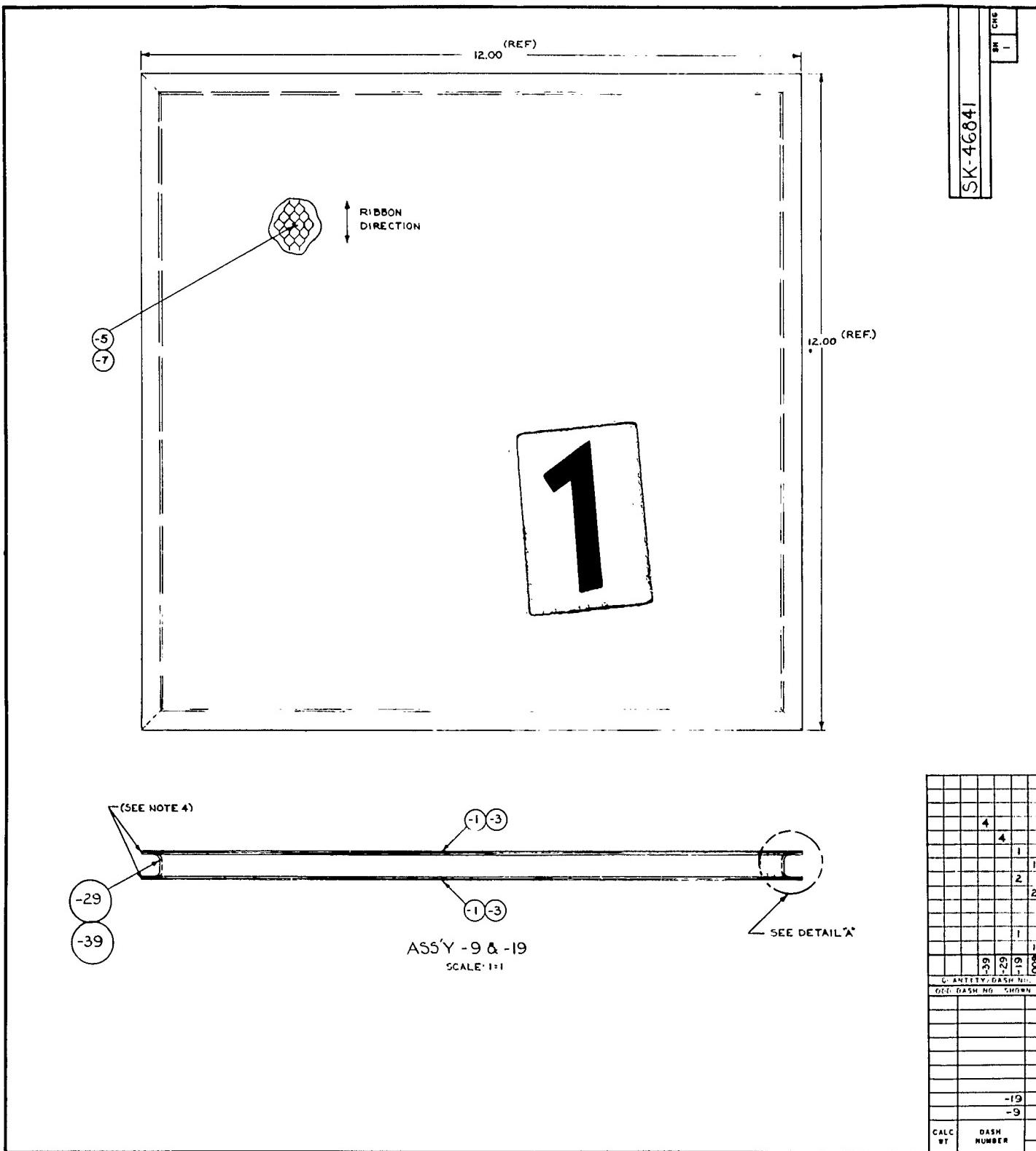
$$f = \frac{M}{t_f h}$$

A nomograph (Fig. 31) was made for determining the panel facing stress from a given airload, panel thickness and facing thickness. Two more curves are given for the determination of the core stress. Figure 32 shows core compressive stress as a function of support diameter and airload. Figure 33 shows core shear stress as a function of support diameter, panel depth and airload. The panels are assumed to be supported on round supports at 0.2 (ℓ) in from the panel edges (ℓ is the panel edge length).

APPENDIX D

TEST PANEL DESIGN DRAWINGS

ER 12249



ER 12249

REVISIONS

SYM	ZONE	DESCRIPTION	DATE	APPROVED

SK-46841

SP CMA -

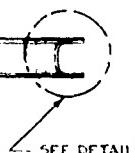
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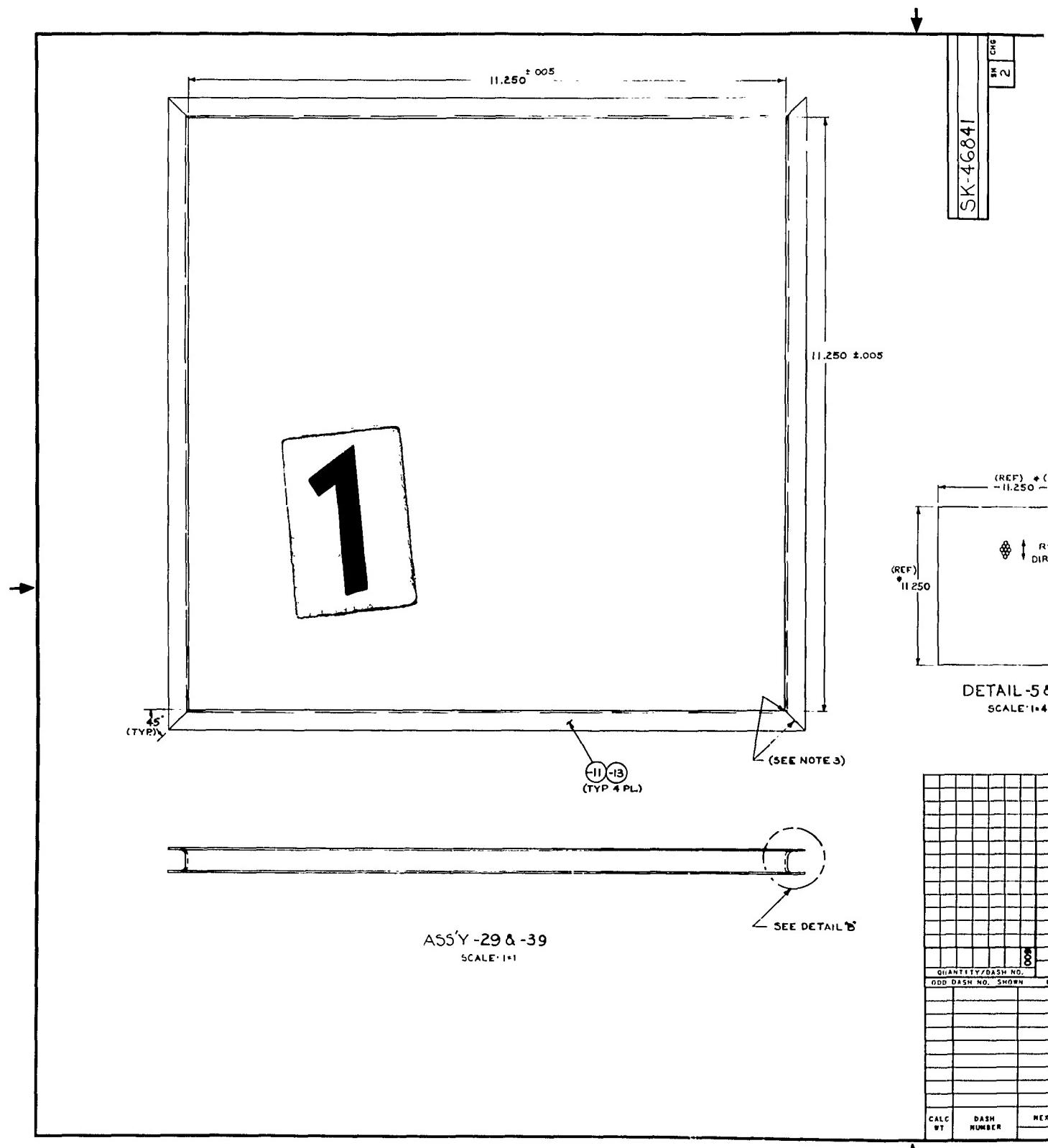
DETAIL "A"
SCALE 4x1

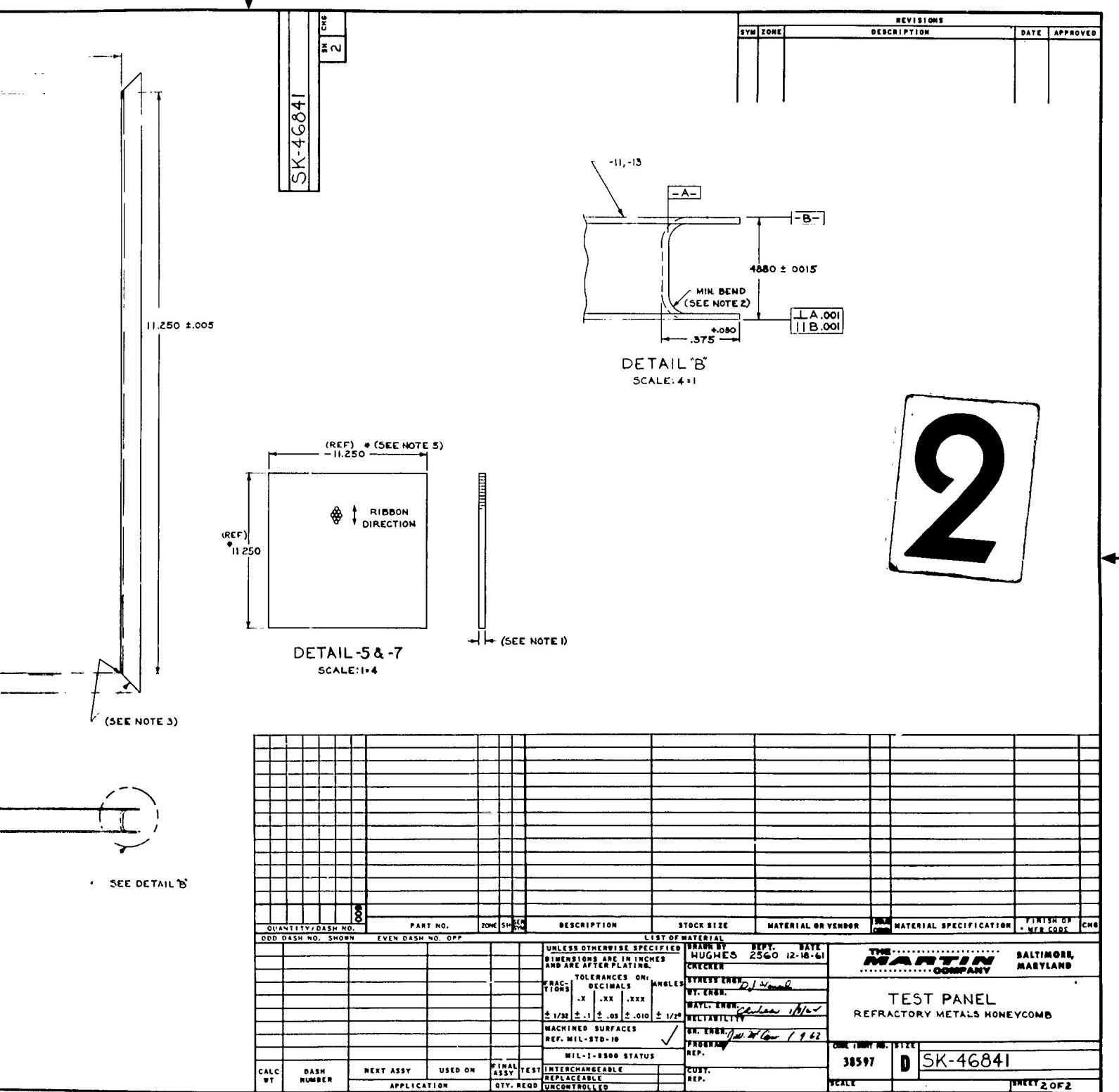
NOTES:

1. HONEYCOMB (-5&-7) MUST MATCH CHANNEL ASSY'S (-29 & -39)
RESP. WITHIN ±.0015
2. MINIMUM BEND RADII WILL BE EXPERIMENTALLY DETERMINED
UPON RECEIPT OF MATERIALS
3. FRAMES TO BE HERMETICALLY SEALED BY WELDING.
(REF. PANEL MFG. PROCEDURES)
4. SKINS TO BE WELDED TO FRAME ASSY'S AT EXTERNAL EDGES
FOR HERMETICAL SEAL (ALL AROUND) (AFTER BRAZING).
(REF. PANEL MFG. PROCEDURES)
5. HONEYCOMB CORE TO BE SIZED TO INSIDE DIMS. OF FRAME ASSY.

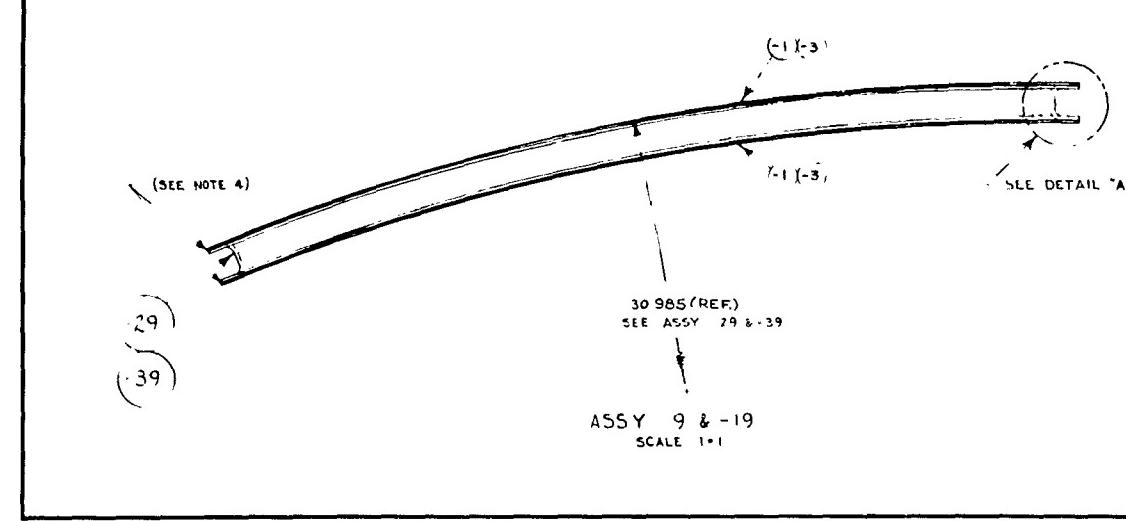
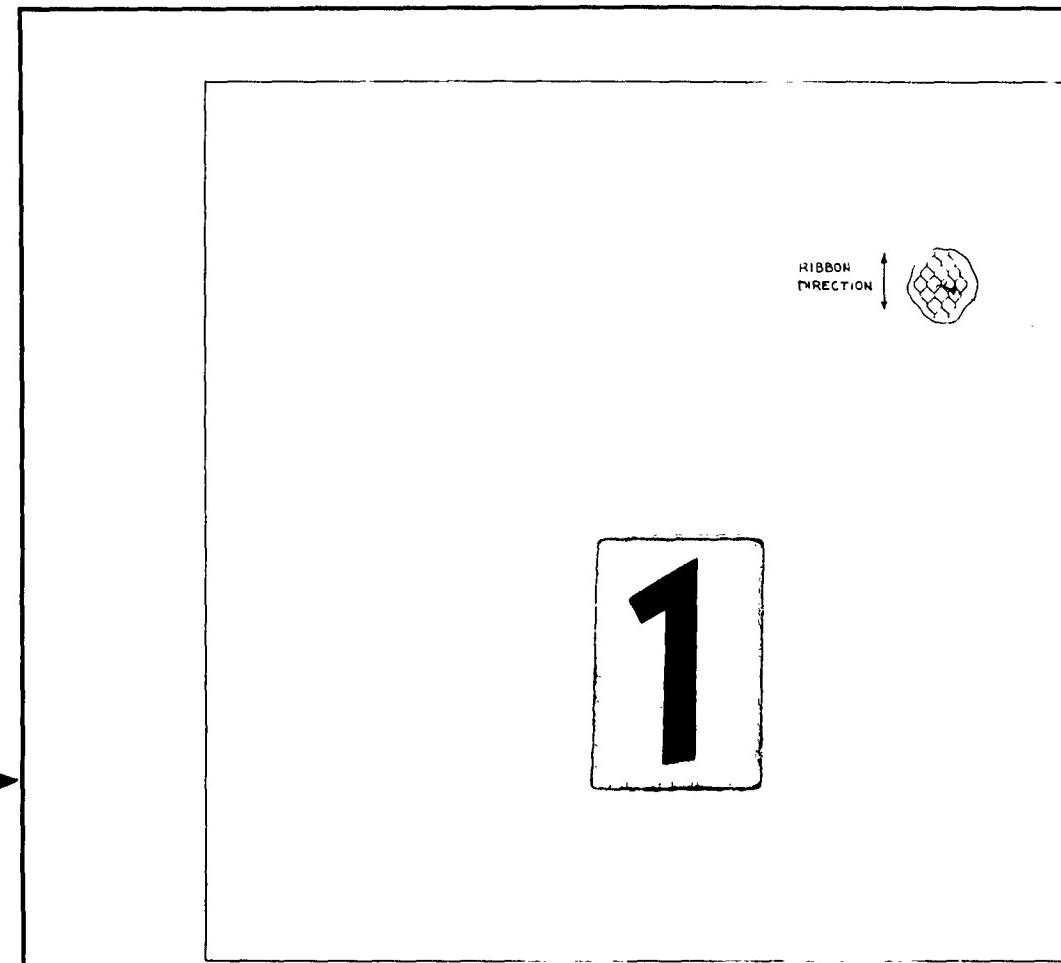
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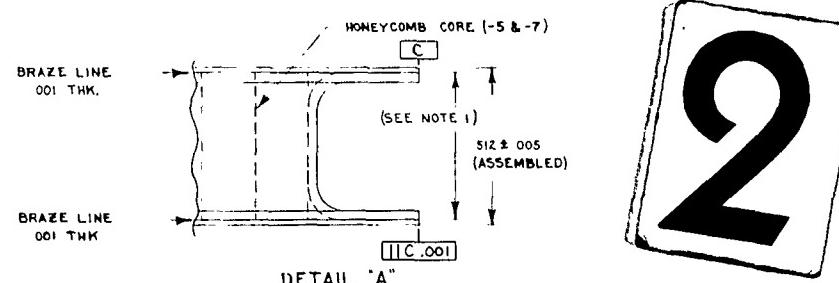


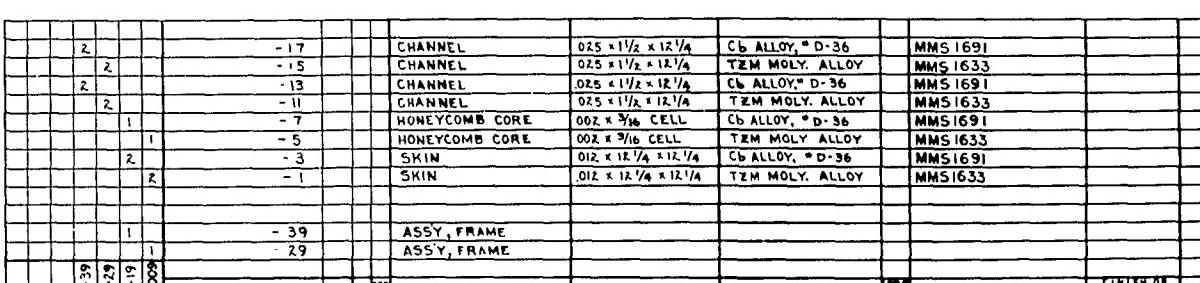
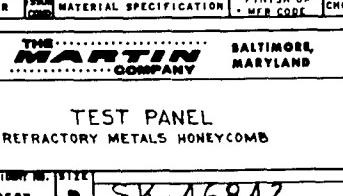
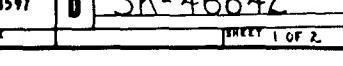


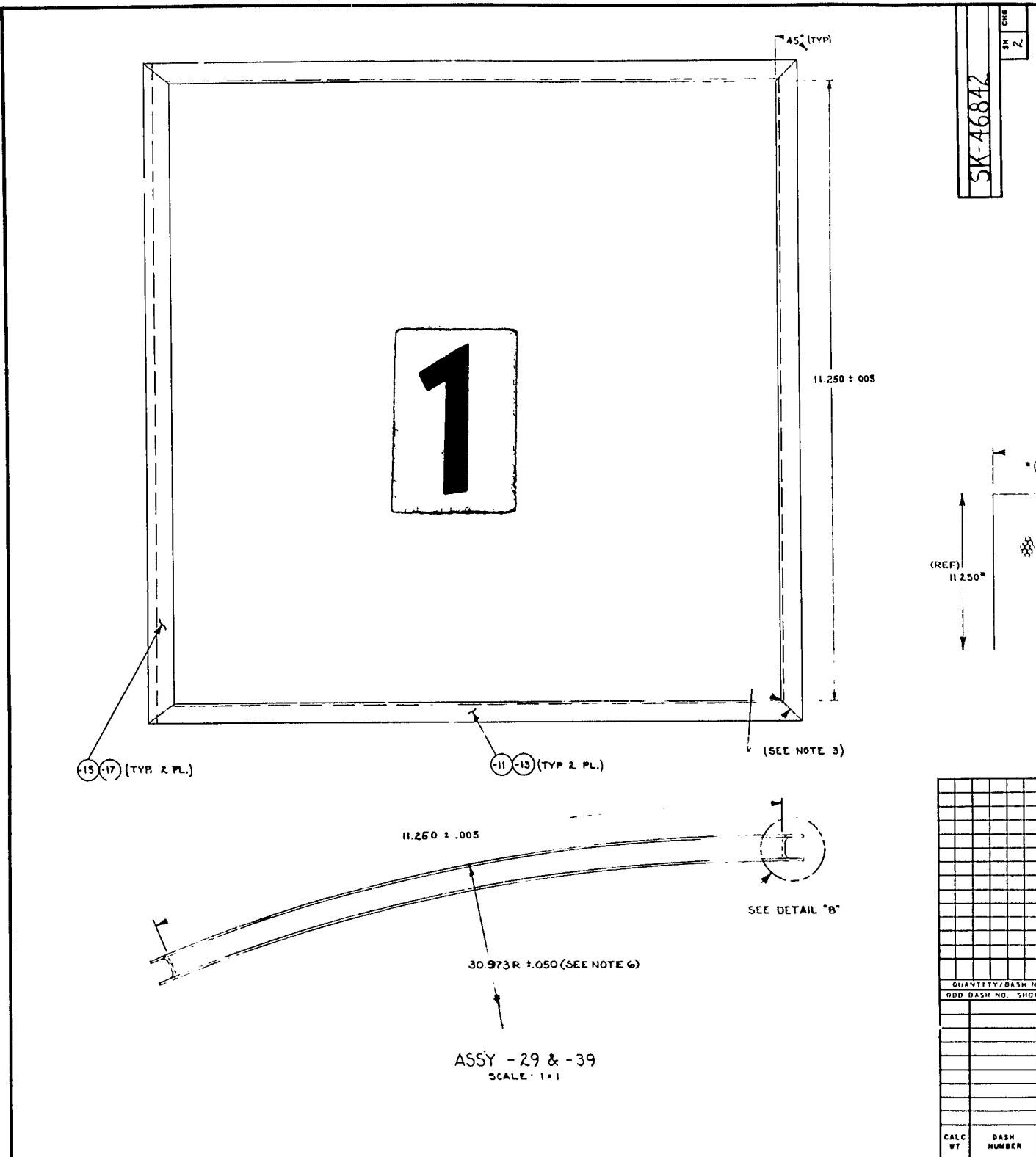
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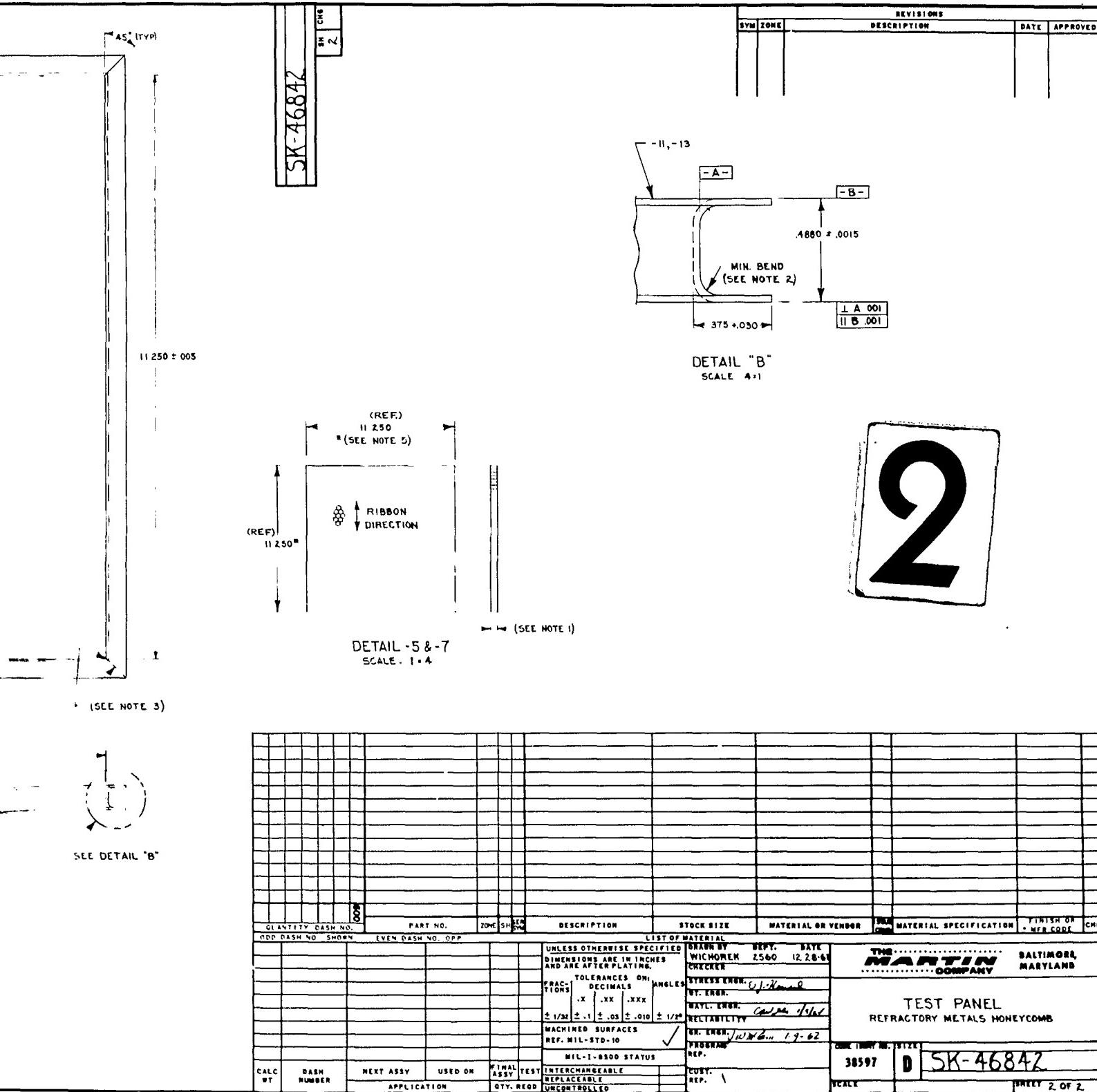


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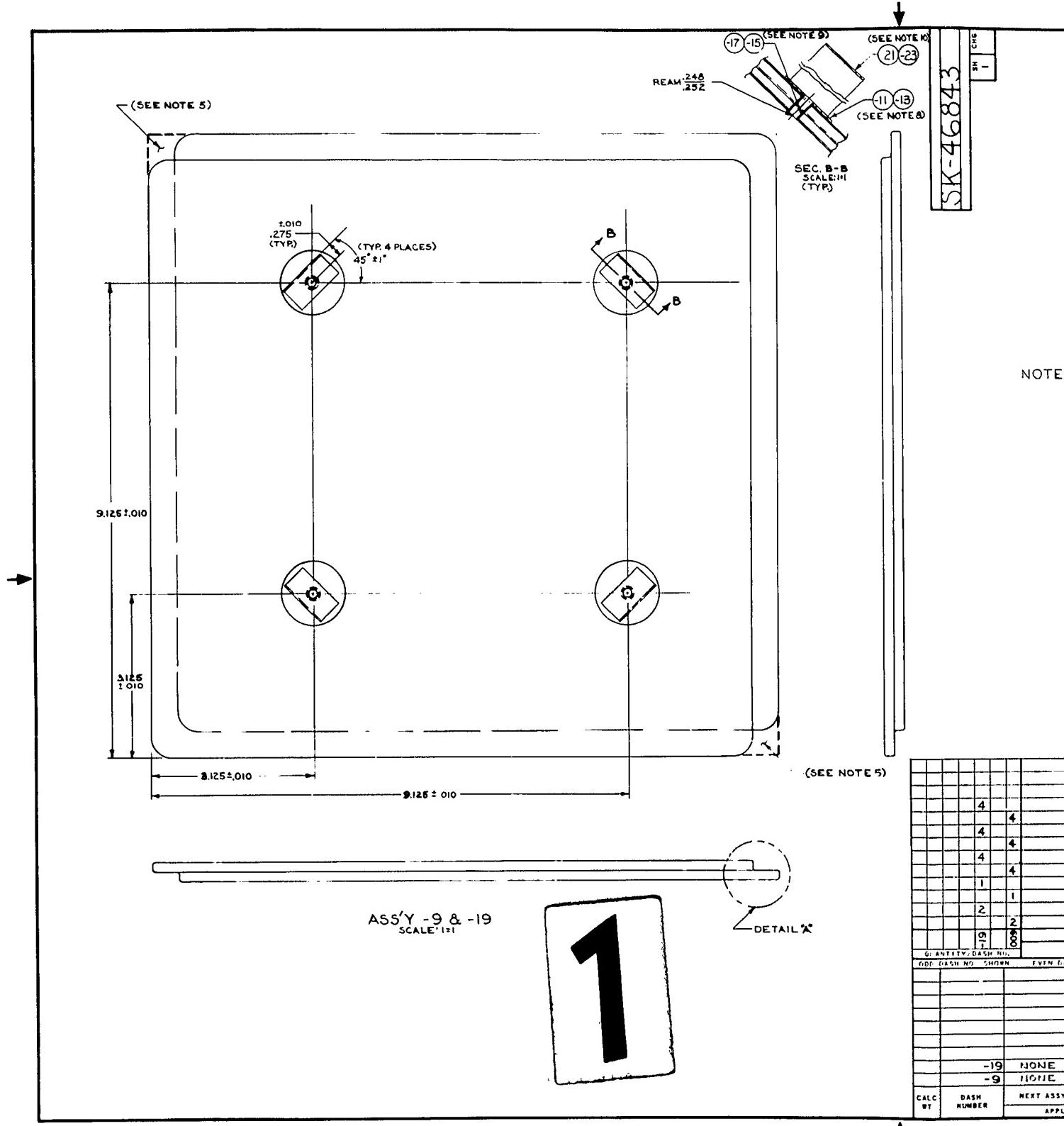
  	SK-46842 <small>CNS SN I</small>	<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th colspan="4" style="text-align: center;">REVISIONS</th> </tr> <tr> <th>SYM</th> <th>ZONE</th> <th>DESCRIPTION</th> <th>DATE APPROVED</th> </tr> </thead> <tbody> <tr> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> </tr> </tbody> </table>  <p style="text-align: center;">DETAIL "A" SCALE 4:1</p>	REVISIONS				SYM	ZONE	DESCRIPTION	DATE APPROVED													<p>12.00 (REF)</p> <p>NOTES:</p> <ol style="list-style-type: none"> 1. HONEYCOMB (-5 & -7) MUST MATCH CHANNEL ASSY'S (-29 & -39) RESP. WITHIN ± .0015 2. MINIMUM BEND RADII WILL BE EXPERIMENTALLY DETERMINED UPON RECEIPT OF MATERIALS 3. FRAMES TO BE HERMETICALLY SEALED BY WELDING (REF. PANEL MFG. PROCEDURES) 4. SKINS TO BE WELDED TO FRAME ASSY'S AT EXTERNAL EDGES FOR HERMETICAL SEAL (ALL AROUND) (AFTER BRAZING) (REF. PANEL MFG. PROCEDURES) 5. HONEYCOMB CORE TO BE SIZED TO INSIDE DIMS. OF FRAME ASSY. 6. CURVED SURFACES MUST MATCH BRAZING FIXTURE WITHIN ± .0015.
REVISIONS																							
SYM	ZONE	DESCRIPTION	DATE APPROVED																				

ALL DETAIL "A"									
									
									
									

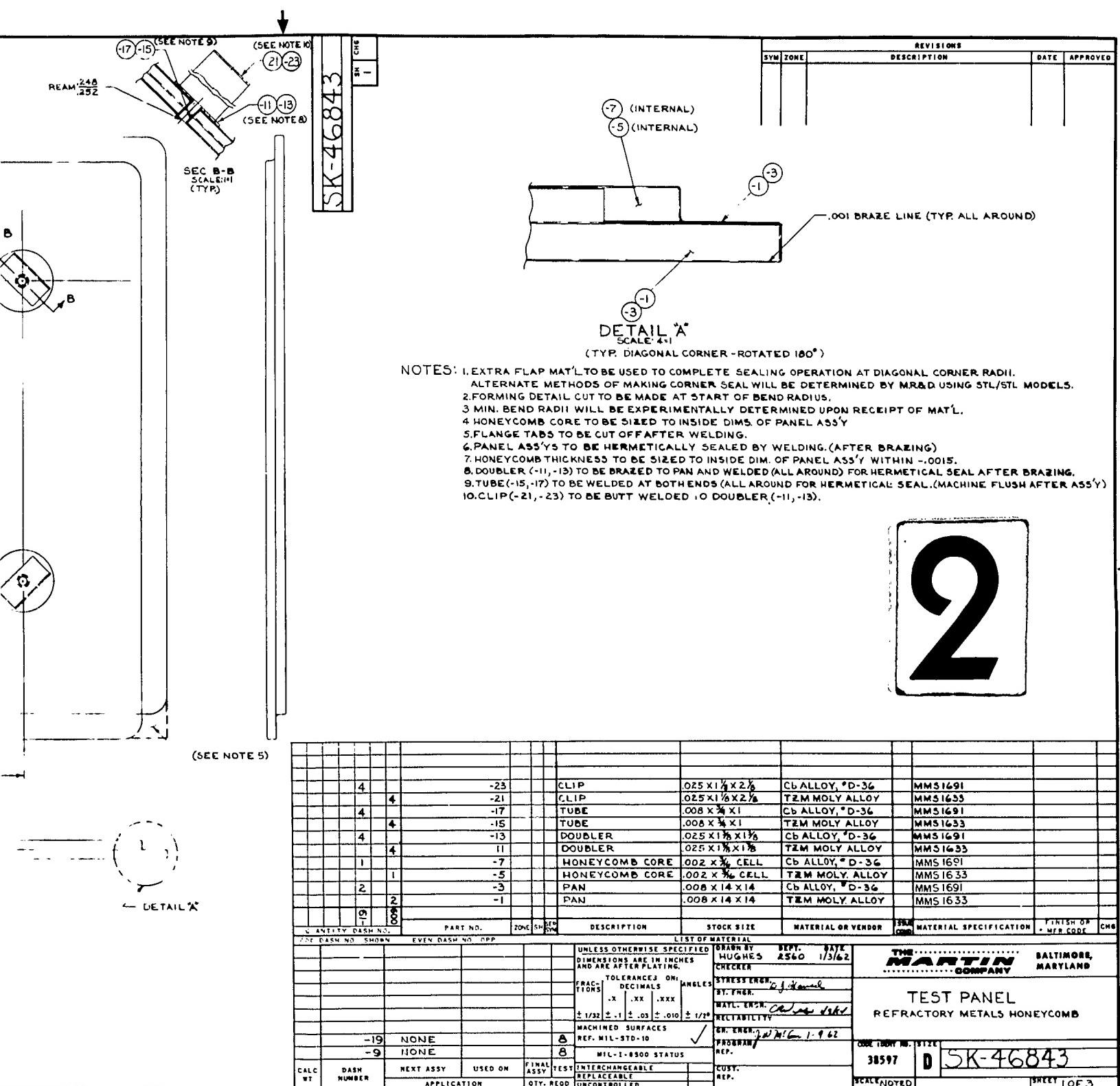


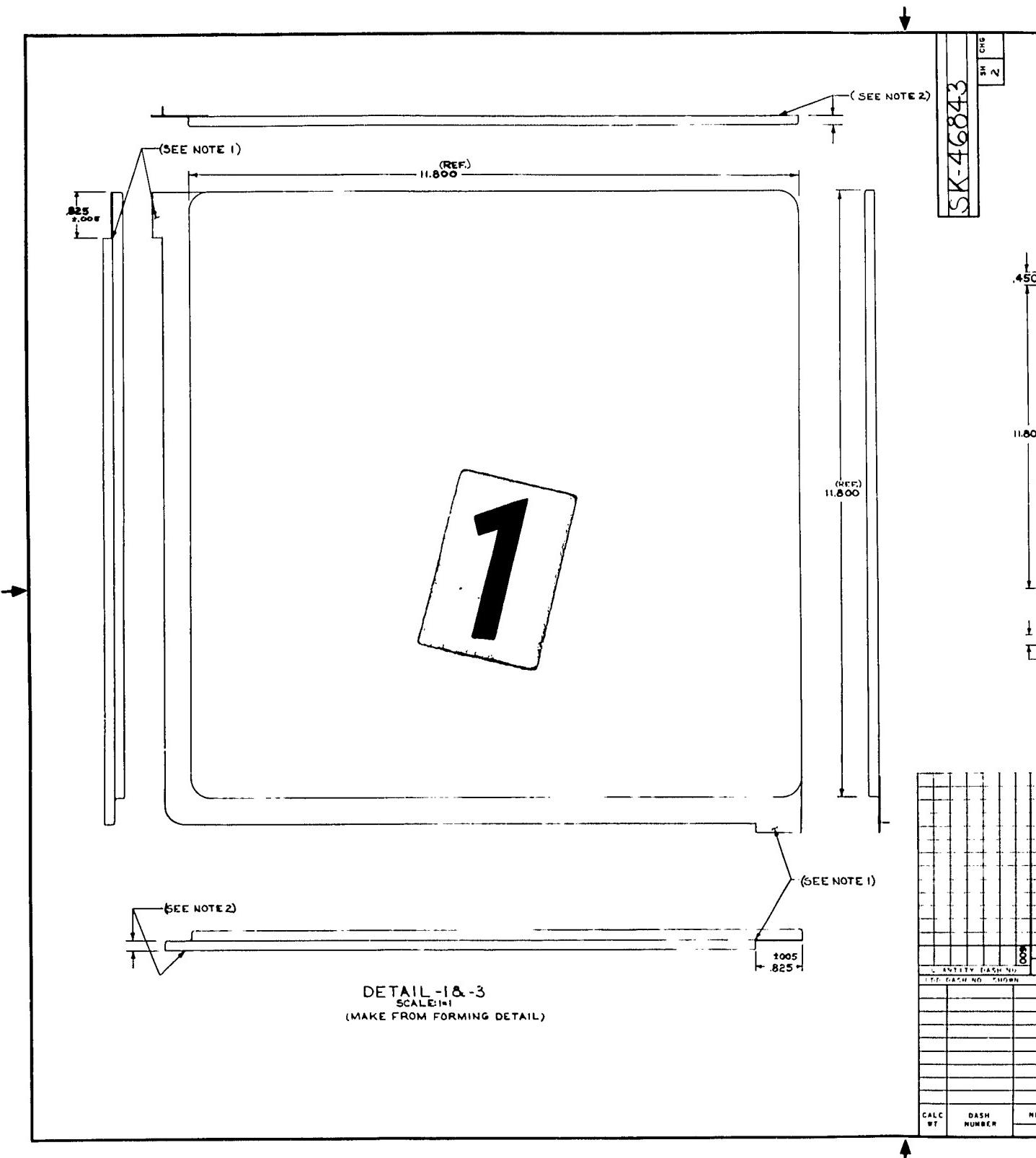


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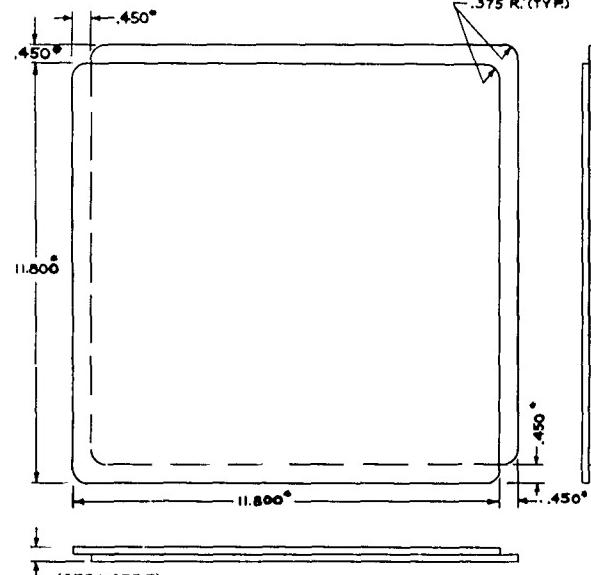
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SK-46843

CHG
E
Z

(SEE NOTE 2)

(W.R.F.)
11.800



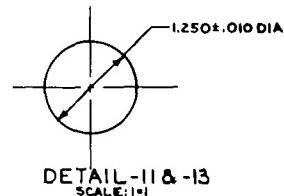
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* ALL DIMS. ARE REF.-(SEE NOTE 4)
SCALE:1:2

(SEE NOTE 1)

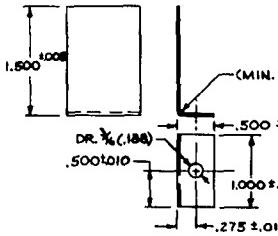
1005
825

REVISIONS		DATE	APPROVED
SYM	ZONE	DESCRIPTION	
		.250 ± .001	
		SEAM WELD (ELECTRON BEAM)	

DE-AIL-15&-17
SCALE:1:1



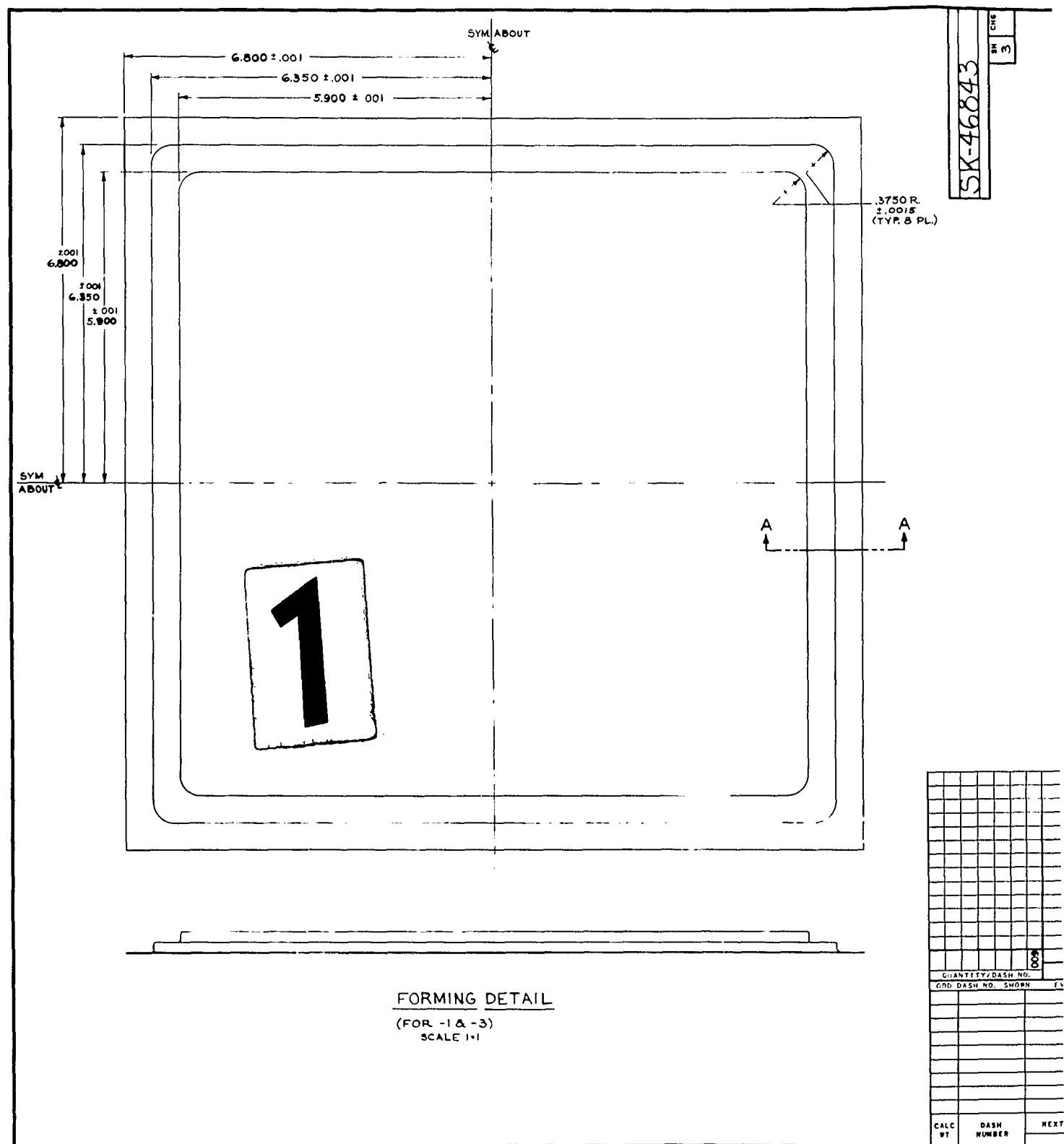
DETAIL -11 & -13
SCALE:1:1



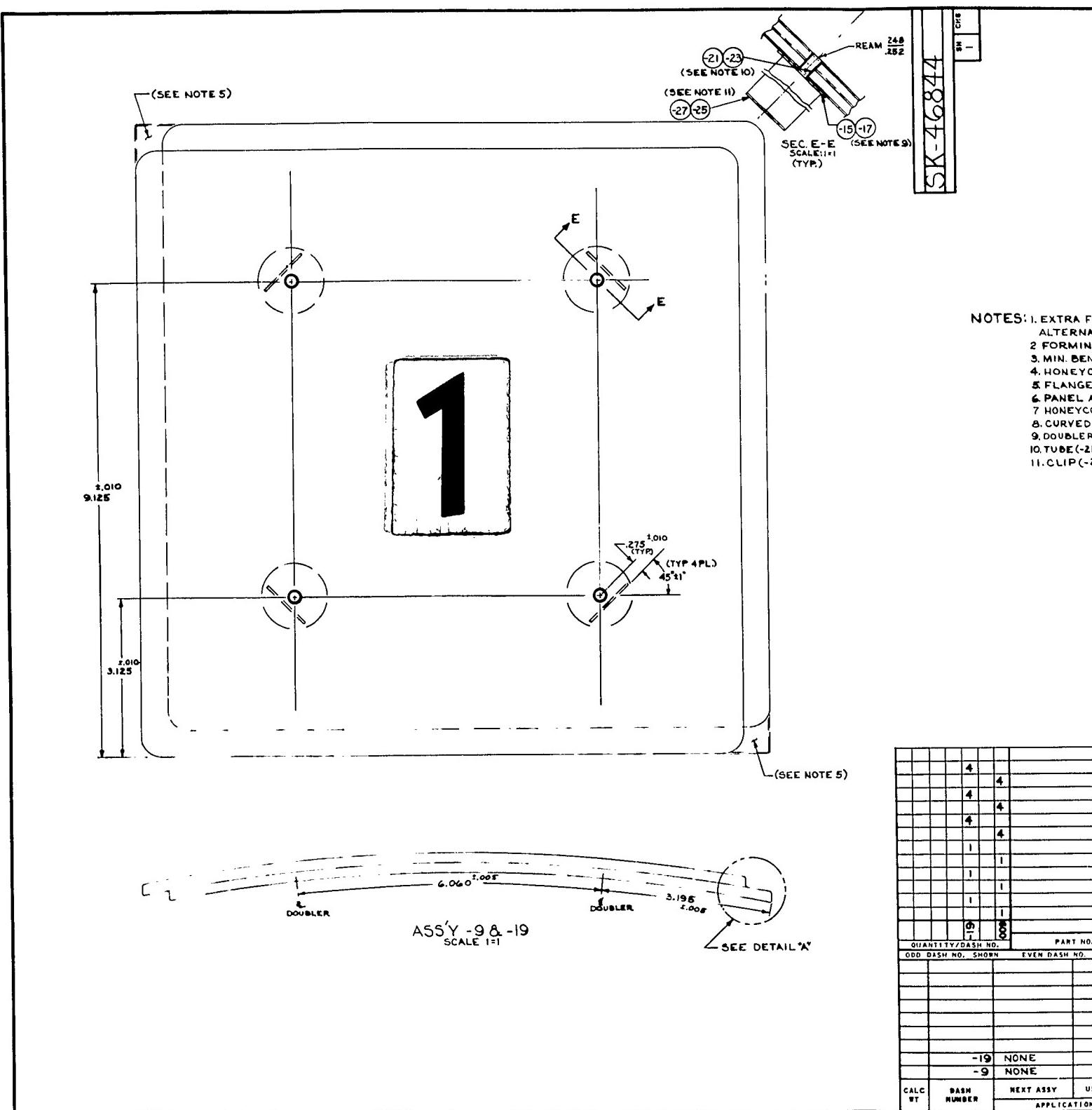
DETAIL -21 & -23
SCALE:1:1

CALC RT	DASH NUMBER	PART NO.	ZONE	SIZE	DESCRIPTION	STOCK SIZE	MATERIAL OR VENDOR	FINISH OR CODE	MATERIAL SPECIFICATION	W.H.R. CODE	CHG		
LIST OF MATERIAL													
					UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AND ARE AFTER PLATING.	DRAWN BY HUGHES	REV. 2960	DATE 1/5/62	THE MARTIN COMPANY				
					TOLERANCES ON: FRAC. TIONS .X .XX .XXX	CHECKER			BALTIMORE, MARYLAND				
					± 1/32 ± .1 ± .05 ± .010 ± 1/4"	TESTER SIGN D. J. Plummer			TEST PANEL				
					MACHINED SURFACES REF. MIL-STD-10	WT. ENGR. MIL. STD. C-100-1/64			REFRACTORY METALS HONEYCOMB				
					MIL-1-8500 STATUS REF. MIL-STD-10	RELATABILITY UR. ENGR. J. D. W. CO. 1-9-62			PROGRAN REP.				
					INTERCHANGEABLE	PROGRAN REP.			CIR. INSTR. NO. 38597				
					REPLACEABLE	COV. REP.			SK-46843				
					UNCONTROLLED	SCALING NOTED			SHEET 2 OF 3				

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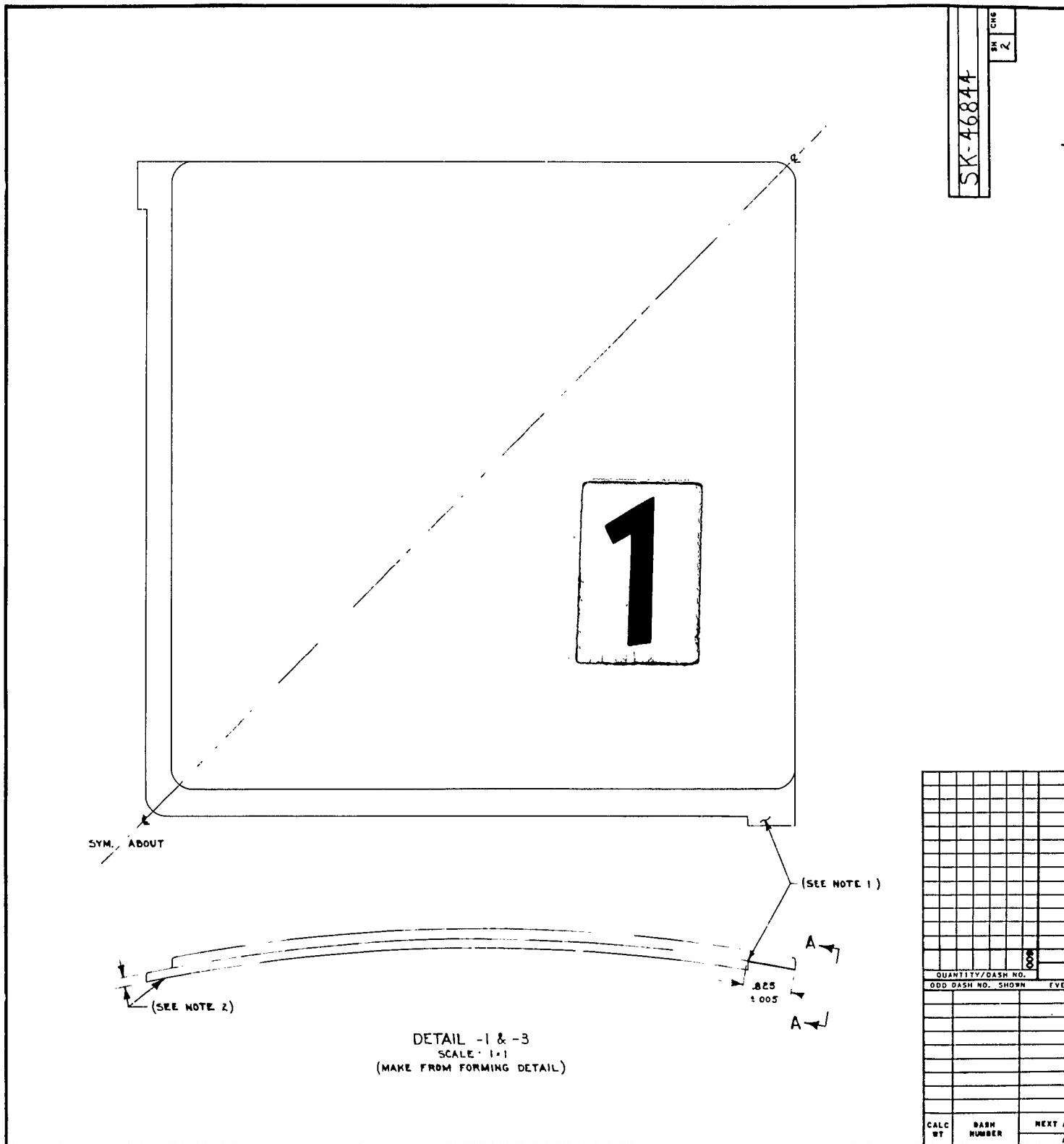
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<p style="text-align: right;">(SEE NOTE 10) (SEE NOTE 11) (-21, -23) (-27, -25) (-15, -17) SEC E-E (SEE NOTES) SCALE: 1:1 (TYP)</p> <p style="text-align: right;">REAM .248 .252</p> <p style="text-align: right;">SK-46844</p>	<p style="text-align: center;">.001 BRAZE LINE (TYP. ALL AROUND)</p> <p style="text-align: center;">DETAIL "A" SCALE: 2:1 (SIM. ASS'Y DIAGONAL CORNER)</p>	<p style="text-align: center;">REVISIONS</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>SYM</th> <th>ZONE</th> <th>DESCRIPTION</th> <th>DATE</th> <th>APPROVED</th> </tr> </thead> <tbody> <tr><td></td><td></td><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td><td></td><td></td></tr> <tr><td></td><td></td><td></td><td></td><td></td></tr> </tbody> </table>	SYM	ZONE	DESCRIPTION	DATE	APPROVED																																																																																																																															
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QUANTITY/DASH NO. SHOWN	PART NO.	ZONE											SH. SYM	DESCRIPTION	STOCK SIZE	MATERIAL OR VENDOR	MATERIAL SPECIFICATION	FINISH OF MFR CODE	CNC																																																																																																																			
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4	-27			CLIP	.025 X 1/8 X 2 1/8	CB ALLOY, D-36	MMS1691																																																																																																																															
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4	-23			TUBE	.008 X 3/8 X 1	CB ALLOY, D-36	MMS1691																																																																																																																															
4	-21			TUBE	.008 X 3/8 X 1	T2M MOLY. ALLOY	MMS1633																																																																																																																															
4	-17			DOUBLER	.025 X 1/8 X 1 1/2	CB ALLOY, D-36	MMS1691																																																																																																																															
4	-15			DOUBLER	.025 X 1/8 X 1 1/2	T2M MOLY. ALLOY	MMS1633																																																																																																																															
1	-13			HONEYCOMB CORE	.002 X 3/4 CELL	CB ALLOY, D-36	MMS1691																																																																																																																															
1	-11			HONEYCOMB CORE	.002 X 3/4 CELL	T2M MOLY ALLOY	MMS1633																																																																																																																															
1	-7			PAN	.008 X 14 X 14	CB ALLOY, D-36	MMS1691																																																																																																																															
1	-5			PAN	.008 X 14 X 14	T2M MOLY ALLOY	MMS1633																																																																																																																															
1	-3			PAN	.008 X 14 X 14	CB ALLOY, D-36	MMS1691																																																																																																																															
1	-1			PAN	.008 X 14 X 14	T2M MOLY ALLOY	MMS1633																																																																																																																															
<p style="text-align: center;">(SEE NOTE 5)</p> <p style="text-align: center;">SEE DETAIL "A"</p> <p style="text-align: center;">3.195 .006</p> <p style="text-align: center;">10.00</p> <p style="text-align: center;">45.51°</p> <p style="text-align: center;">(TYP. 4 PL.)</p> <p style="text-align: center;">27.75 (TYP)</p>																																																																																																																																						

ER 12249



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<p>SK-46844 REV C WZ</p> <p>(SEE NOTE 1)</p> <p>A</p> <p>.825 1.005</p> <p>A</p> <p>VIEW A-A SCALE: 1:1</p> <p>DETAIL -11 & -13 * ALL DIM ARE REF. - (SEE NOTE 4) SCALE: 1:2</p> <p>DETAIL -21 & -23 SCALE: 1:1</p> <p>DETAIL -15 & -17 SCALE: 1:1</p> <p>DETAIL -25 & -27 SCALE: 1:1</p> <p>(SEE NOTE 7)</p>	<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th colspan="4"></th> <th colspan="4">REVISIONS</th> </tr> <tr> <th>SYM</th> <th>ZONE</th> <th>DESCRIPTION</th> <th>DATE</th> <th colspan="4">APPROVED</th> </tr> </thead> <tbody> <tr> <td></td> <td></td> <td></td> <td></td> <td colspan="4"></td> </tr> </tbody> </table> <p>TEST PANEL REFRACTORY METALS HONEYCOMB</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th rowspan="2">QUANTITY/DASH NO. ODD DASH NO. SHOWN</th> <th rowspan="2">PART NO.</th> <th rowspan="2">ZONE SHOWN</th> <th rowspan="2">DESCRIPTION</th> <th rowspan="2">STOCK SIZE</th> <th rowspan="2">MATERIAL OR VENDOR</th> <th rowspan="2">MATERIAL SPECIFICATION</th> <th rowspan="2">FINISH OR MFR CODE</th> <th rowspan="2">CHG</th> <th colspan="4">LIST OF MATERIAL</th> </tr> <tr> <th>EVEN DASH NO. OFF</th> <th>UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AND ARE AFTER PLATING.</th> <th>DRAWN BY WICHORNEM X960 1-5-62</th> <th>TYPE MARTIN COMPANY</th> <th>BALTIMORE, MARYLAND</th> </tr> </thead> <tbody> <tr> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>TOLERANCES ON DIMENSIONS .X .XX .XXX</td> <td>STRESS RELIEF WT. ENR.</td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>± 1/32 ± .1 ± .05 ± .010 ± 1/32</td> <td>WT. ENR. 04/24/62</td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>MACHINED SURFACES REF. MIL-STD-10</td> <td>ELASTICITY</td> <td></td> </tr> <tr> <td></td> <td>WT. ENR. 04/24/62</td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>MIL-I-8500 STATUS</td> <td>PROGRAM</td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>REP.</td> <td></td> <td></td> </tr> <tr> <td>CALC BT</td> <td>DASH NUMBER</td> <td>NEXT ASSY</td> <td>USED ON</td> <td>FINAL ASSY TEST</td> <td>INTERCHANGEABLE</td> <td>CUST. REP.</td> <td>ITEM NO. SIZE</td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> <td></td> <td>REPLACEABLE</td> <td></td> <td>38597</td> <td>D</td> <td>SK-46844</td> </tr> <tr> <td></td> <td></td> <td>APPLICATION</td> <td>QTY. READ</td> <td>UNCONTROLLED</td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> </tbody> </table>					REVISIONS				SYM	ZONE	DESCRIPTION	DATE	APPROVED												QUANTITY/DASH NO. ODD DASH NO. SHOWN	PART NO.	ZONE SHOWN	DESCRIPTION	STOCK SIZE	MATERIAL OR VENDOR	MATERIAL SPECIFICATION	FINISH OR MFR CODE	CHG	LIST OF MATERIAL				EVEN DASH NO. OFF	UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AND ARE AFTER PLATING.	DRAWN BY WICHORNEM X960 1-5-62	TYPE MARTIN COMPANY	BALTIMORE, MARYLAND										TOLERANCES ON DIMENSIONS .X .XX .XXX	STRESS RELIEF WT. ENR.											± 1/32 ± .1 ± .05 ± .010 ± 1/32	WT. ENR. 04/24/62											MACHINED SURFACES REF. MIL-STD-10	ELASTICITY												WT. ENR. 04/24/62											MIL-I-8500 STATUS	PROGRAM											REP.			CALC BT	DASH NUMBER	NEXT ASSY	USED ON	FINAL ASSY TEST	INTERCHANGEABLE	CUST. REP.	ITEM NO. SIZE							REPLACEABLE		38597	D	SK-46844			APPLICATION	QTY. READ	UNCONTROLLED						<p>WZ</p> <p>NOTE 2)</p> <p>.375 R° (TYP)</p> <p>.450°</p> <p>11.800"</p> <p>12.000"</p> <p>.450°</p> <p>.450°</p> <p>.450°</p> <p>.450°</p> <p>(SEE NOTE 7)</p> <p>.375 R° (TYP)</p> <p>.250 ± .001</p> <p>SEAM WELD (ELECTRON BEAM)</p> <p>L250 ± .010 DIA</p> <p>(MIN. BEND) (SEE NOTE 3)</p> <p>DR. 3/16 (.188)</p> <p>.500 ± .010</p> <p>.800 ± .010</p> <p>.1000 ± .010</p> <p>.275 ± .010</p>
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1

5K-46844

SYM. ABOUT

(SEE NOTE 2)

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825
9005

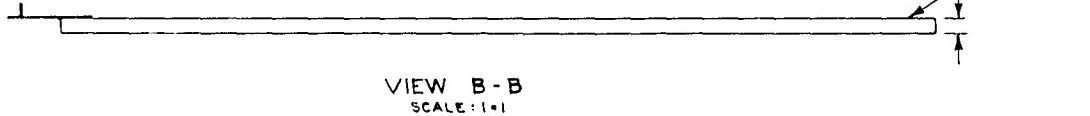
B-1

DETAIL - 5 & -7
SCALE: 1:1
(MAKE FROM FORMING DETAIL)

SK-46844

BR CRW
3

REVISIONS			
SYM	ZONE	DESCRIPTION	DATE APPROVED



VIEW B-B
SCALE: 1:1

2

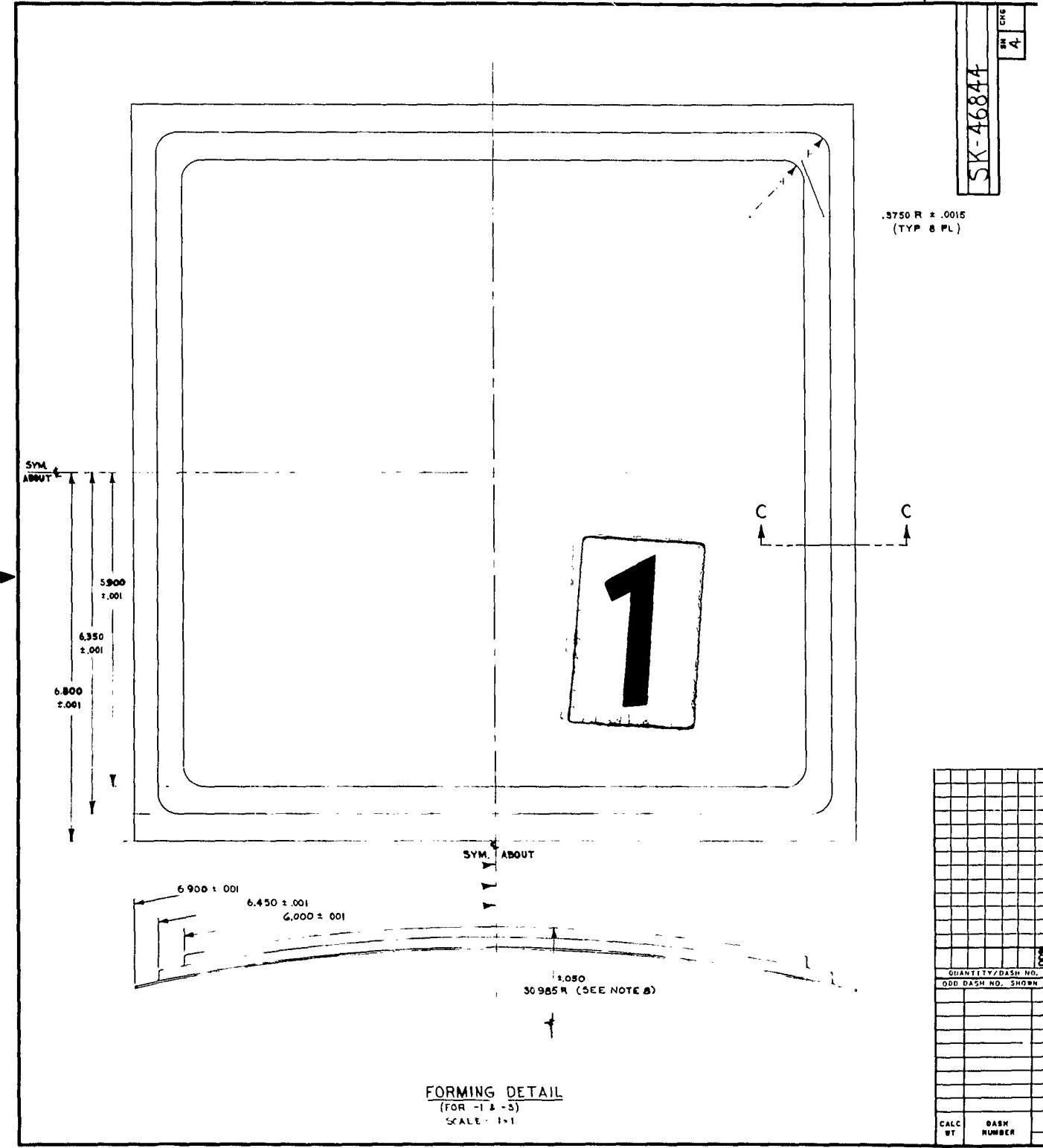
(SEE NOTE 1)

B

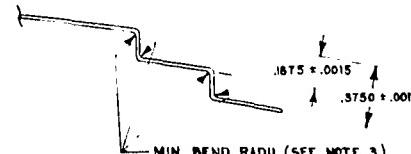
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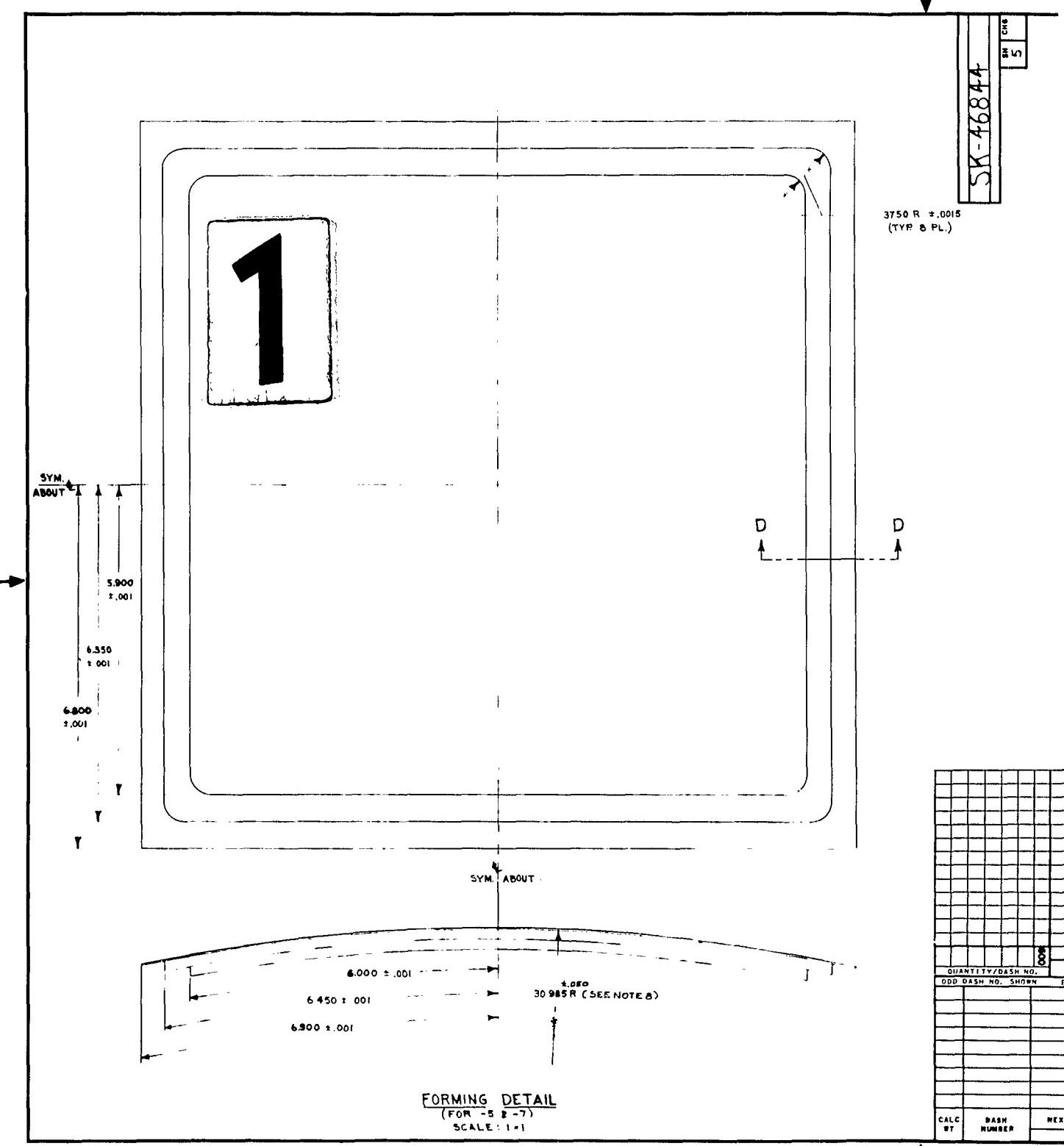
QUANTITY	DASH NO.	PART NO.	ZONE	DESCRIPTION	STOCK SIZE	MATERIAL OR VENDOR	MATERIAL SPECIFICATION	FINISH OF	ITEM NO. - MFG CODE	
									ITEM NO.	MFG CODE
LIST OF MATERIAL										
				UNLESS OTHERWISE SPECIFIED	DRAWN BY	BPFY.	DATE			
				BIMINENTIAL IN INCHES	WICHOREK	R560	1-3-62			
				AND ARE INTERPLATING	CHICKER					
				FRACTIONAL TOLERANCES ON	STRESS TEST	0.64				
				DECIMALS	WT. TEST					
				X X X X X X X X	WT. TEST					
				± .00 ± .00 ± .00 ± .00	WT. TEST					
				MACHINED SURFACES	WT. TEST					
				REF. MIL-STD-10	WT. TEST					
					MIL-1-8800 STATUS					
					INTERCHANGEABLE	CUST.				
					REPLACEABLE	REP.				
					UNCONTROLLED	REP.				
CALC WT	DASH NUMBER	NEXT ASSY USED ON	FINAL ASSY TEST						ITEM NO. SIZE	
		APPLICATION	QTY. REQD						38597	D SK-46844
									SCALE	DRAWING 3 OF 5



ER 12249

SK-46844	REV. A	REVISIONS	DATE	APPROVED																																																																						
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015 L)																																																																										
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ER 12249



ER 12249

SK-46844

CH6

5

3750 R ±.0015
(TYP & PL)

REVISIONS			
SYM	ZONE	DESCRIPTION	DATE

A MIN. BEND RADII (SEE NOTE 3)

1675 ± .0015 3750 ± .0015

SEC. D-D
(TYP 4 SIDES)
SCALE 2:1



QTY.	DASH NO.	PART NO.	ZONE	SH	DESCRIPTION	STOCK SIZE	MATERIAL OR VENDOR	MATERIAL SPECIFICATION	FINISH OR MFR CODE	CH6
8										
LIST OF MATERIAL										
<p>UNLESS OTHERWISE SPECIFIED DRAWN BY DEPT. DATE DIMENSIONS ARE IN INCHES WICHOREK 2560 1-3-62 AND ARE AFTER PLATING. CHECKER</p> <p>TOLERANCES ON STRESS ENTH. <i>D146-62</i> ITEMS .X .XX .XXX BY. ENTH. DECIMALS ANGLES</p> <p>2 1/32 2 .1 ± .05 ± .010 ± 1/32 RELIABILITY REF. MIL-STD-10 BY. ENTH. <i>as required</i></p> <p>MACHINED SURFACES ✓ PROGRAM REF. MIL-STD-10 BY. ENTH. <i>JW Mfg 1-9-62</i></p> <p>MIL-I-8580 STATUS REP.</p>										
CALC WT	DASH NUMBER	NEXT ASSY	USED ON	FINAL TEST	INTERCHANGEABLE	REPLACEABLE	COST.	ITEM NO. 30597	D SK-46844	RECALL
		APPLICATION	GT.Y. RECD	UNCONTROLED		REP.				NOTE 5 OF 5

<p>MARTIN</p> <p>UNCLASSIFIED</p>	<p>MARTIN</p> <p>UNCLASSIFIED</p>	<p>MARTIN</p> <p>UNCLASSIFIED</p>
<p>Martin Marietta Corporation, Baltimore, Maryland, MANUFACTURING METHODS AND DESIGN PROCEDURES FOR BRAZED REFRACTORY METAL HONEYCOMB PANELS by J. W. McCown, C. R. Wilks and L. J. Gagola. (Proj. 7-937) (ASD TR -7-937) (Contract AF 33(657)-7276), Unclassified report.</p> <p>Honeycomb sandwich panels using molybdenum and columbium core and facings can be brazed to provide light weight structural coverings for high temperature application on an aerospace vehicle. The panel configurations selected for fabrication simulate a hot structural and a radiant heat shield application. Manufacturing processes and procedures developed in the program will be used to fabricate test panels. Elevated temperature tests will determine thermal and structural capabilities of the test panels.</p> <p>1. Material Processing 2. Sandwich Structures 3. Refractory Metals 4. Brazing 5. Manufacturing Methods 6. High Temperature Testing</p> <p>I. McCown, J. W. II. Martin Marietta Corporation III. AF 33(657)-7276 IV. ASD Project 7-937 V. Materials and Manufacturing Technology Laboratory</p>	<p>Martin Marietta Corporation, Baltimore, Maryland, MANUFACTURING METHODS AND DESIGN PROCEDURES FOR BRAZED REFRACTORY METAL HONEYCOMB PANELS by J. W. McCown, C. R. Wilks and L. J. Gagola. (Proj. 7-937) (ASD TR -7-937) (Contract AF 33(657)-7276), Unclassified report.</p> <p>Honeycomb sandwich panels using molybdenum and columbium core and facings can be brazed to provide light weight structural coverings for high temperature application on an aerospace vehicle. The panel configurations selected for fabrication simulate a hot structural and a radiant heat shield application. Manufacturing processes and procedures developed in the program will be used to fabricate test panels. Elevated temperature tests will determine thermal and structural capabilities of the test panels.</p> <p>1. Material Processing 2. Sandwich Structures 3. Refractory Metals 4. Brazing 5. Manufacturing Methods 6. High Temperature Testing</p> <p>I. McCown, J. W. II. Martin Marietta Corporation III. AF 33(657)-7276 IV. ASD Project 7-937 V. Materials and Manufacturing Technology Laboratory</p>	<p>Martin Marietta Corporation, Baltimore, Maryland, MANUFACTURING METHODS AND DESIGN PROCEDURES FOR BRAZED REFRACTORY METAL HONEYCOMB PANELS by J. W. McCown, C. R. Wilks and L. J. Gagola. (Proj. 7-937) (ASD TR -7-937) (Contract AF 33(657)-7276), Unclassified report.</p> <p>Honeycomb sandwich panels using molybdenum and columbium core and facings can be brazed to provide light weight structural coverings for high temperature application on an aerospace vehicle. The panel configurations selected for fabrication simulate a hot structural and a radiant heat shield application. Manufacturing processes and procedures developed in the program will be used to fabricate test panels. Elevated temperature tests will determine thermal and structural capabilities of the test panels.</p> <p>1. Material Processing 2. Sandwich Structures 3. Refractory Metals 4. Brazing 5. Manufacturing Methods 6. High Temperature Testing</p> <p>I. McCown, J. W. II. Martin Marietta Corporation III. AF 33(657)-7276 IV. ASD Project 7-937 V. Materials and Manufacturing Technology Laboratory</p>
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